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Effects of Aerial Spraying of Forestry Herbicides on Aquatic Ecosystems

Part II. Baseline Physical and Chemical Characterization of Experimental Study Ponds

By L.G. Goldsborough and D.J. Brown

Manitoba
Environment and
Workplace Safety
and Health

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Abstract

As part of a three-year study examining some potential effects of herbicide use in forest management on adjacent aquatic ecosystems, baseline physical and chemical characteristics of six small ponds (surface area 0.2-0.7 ha, mean depth < 1.5 m) located in the southeastern boreal forest near Pine Falls, Manitoba were monitored in 1985. Nine to twelve surficial sediment samples were collected from each pond in late September and analyzed for textural composition and concentrations of sodium, potassium, calcium, magnesium, iron, manganese, sulphate, carbonate, nitrate and phosphate. Salinity, pH and organic matter content of these samples were also determined. Surface (10-15 cm) water samples were collected at weekly intervals from May to October and one date in December. These were analyzed for true color, pH, conductivity, alkalinity and concentrations of sodium, potassium, calcium, magnesium, iron, manganese, chloride, fluoride, sulphate, ammonia-nitrogen, nitrate/nitrite-nitrogen, total Kjeldahl nitrogen, total phosphorus, silica and dissolved organic carbon. Measurements of water transparency (Secchi depth), air and surface water temperature and water depth at a fixed location in each pond were also made weekly. Climatic data (daily incident light, wind speed and direction, mid-day air temperature, daily minimum and maximum air temperature, relative humidity and daily precipitation) were collected from a station in the Pine Falls townsite.

Despite inter-pond differences in several of the above parameters, the ponds were most similar chemically to lakes in the Nopiming and Whiteshell areas. The study ponds were more concentrated than lakes in the Experimental Lakes Area in northwestern Ontario but less so than Lake Winnipeg. These data support the conclusion that waters in the area immediately east of Lake Winnipeg tend to be more chemically enriched than those located farther within the Precambrian Shield.

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1.0 Introduction

This project was initiated by the Water Standards and Studies Section of the Department of Environment and Workplace Safety and Health under the terms of the Canada-Manitoba Forest Renewal Agreement. The objective of the three-year project is to examine potential effects of herbicide usage in silvicultural practice on the productivity of adjacent aquatic plant communities.

In an earlier report (Goldsborough & Brown 1986), the rationale used in the choice of six ponds and the specific objectives of the first year of study (before experimental manipulation of the ponds) was provided, as well as descriptions of the analytical methods employed. This report describes climatic features of the study area and characterizes the baseline physical and chemical differences between the ponds.

2.0 Site Climatic Characterization

Ambient climatic parameters were monitored routinely at a station in the town of Pine Falls, Manitoba (ca. 12-25 km distance from study ponds). An electronic anemometer and light sensor were mounted on a south-facing steel tower and were unobstructed in all directions. Cumulative daily rainfall and mid-day air temperature were measured from a height of approximately 1 meter above the ground surface.

2.1 Daily Integrated Light

A solar monitor was deployed at the Pine Falls site on 11 June, 1985 (cumulative yearday 162) at 1030 Central Daylight Time (CDT) and recorded total light received between the wavelengths of 400 and 700 nm at 0.5-3 hour intervals until its removal on 28 October, 1985 (day 301). Figure 1 presents some typical daily light profiles generated from these data. Despite fluctuations resulting from temporally variable cloud cover, cumulative daily light data (Figure 2A) show that light receipt increased slightly within the first 20 days of monitoring to a maximum of 63.14 $E/m^2/day$ on 1 July (day 182) and decreased thereafter (Table 1).

2.2 Wind Speed & Direction

Wind speed at the Pine Falls site (1300 CDT) fluctuated between 0 and 40 km/hr during the 3.5-month period of observation (Figure 2B). There was some indication that wind speed decreased over time; monthly means ranged from 17 km/hr (June) to 12 km/hr (September) (Table 1). The prevailing wind direction during the study period was from the northwest (37% of days) or west-northwest (13%) (Figure 3).

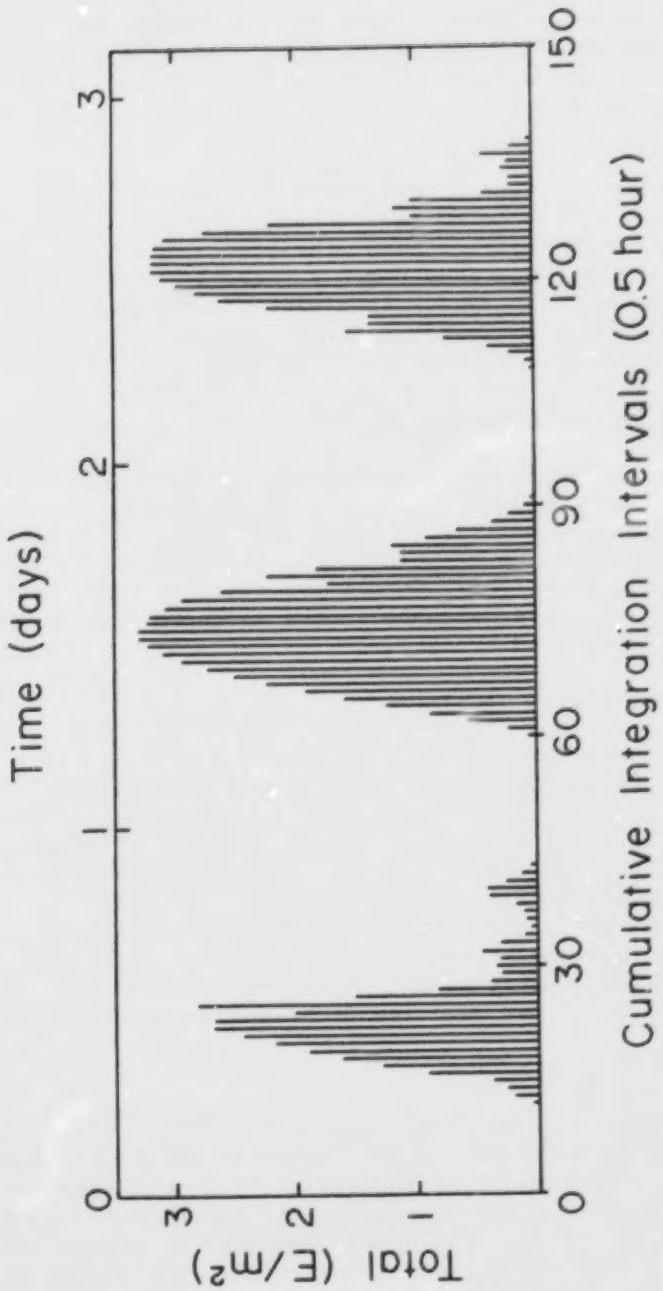

Figure 1: Typical diurnal profiles of photosynthetically available light (400-700 nm) reconstructed from 0.5 hour integrated totals. The data depicted were collected between 16 and 18 July, 1985 (ca. 150 integration periods) and represent cumulative receipts of 27.22, 55.80 and 45.00 E/m²/day respectively.

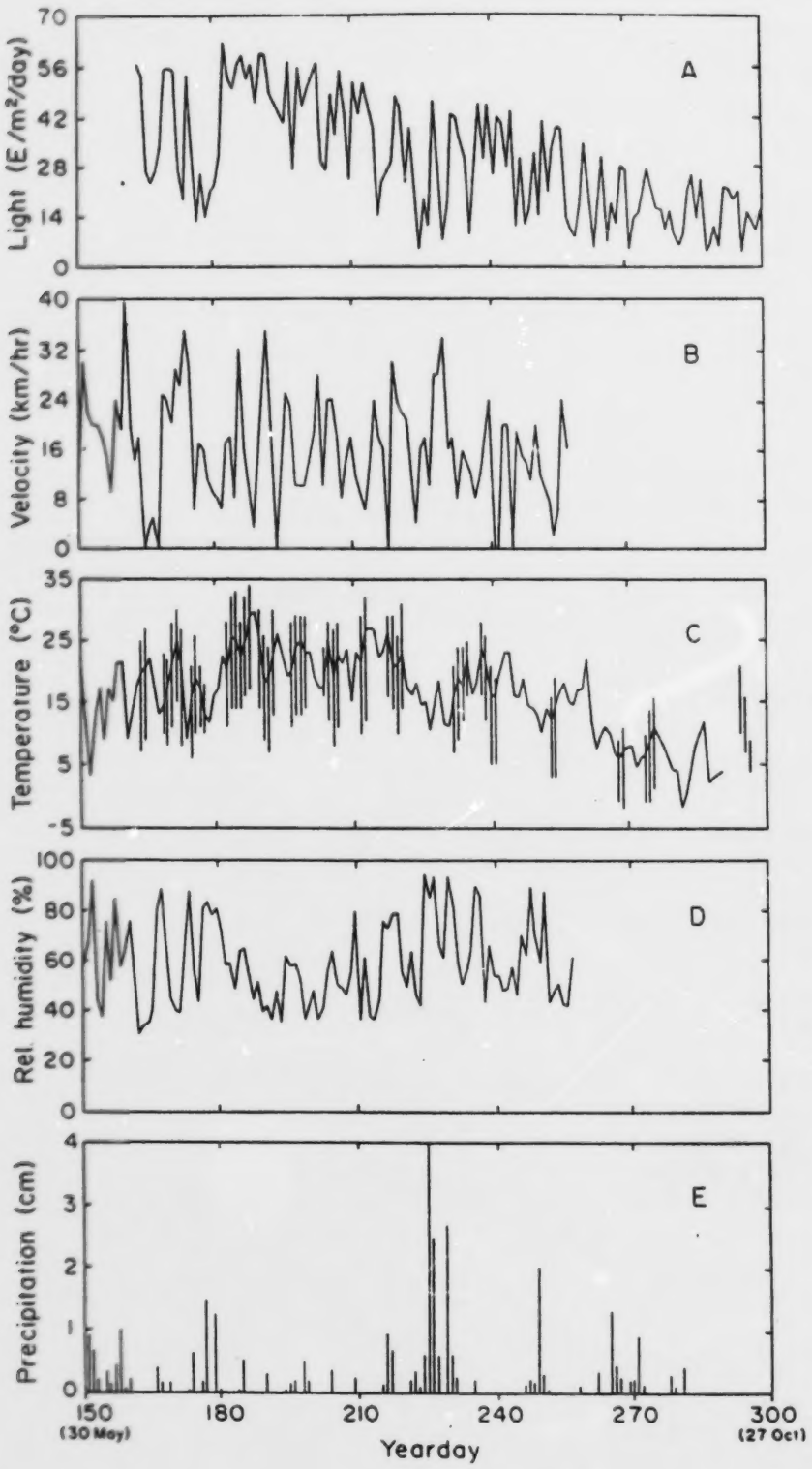

Figure 2: Daily climatic parameters measured at the Pine Falls site between June and October, 1985.
A: Cumulative daily light
B: Mid-day wind speed
C: Mid-day air temperature and daily minima and maxima (vertical bars)
D: Relative Humidity
E: Cumulative daily precipitation

Table 1: Monthly means (and total precipitation) of climatic data; Pine Falls, Manitoba (50° 34′ N, 96° 13′ W) - 1985

Parameter	June	July	August	Sept.	Oct.	Total
daily light ($E/m^2/day$)	33.96[1]	48.13	30.29	21.35	14.48[2]	-
wind speed (km/hr)	17	16	16	12[3]	-	-
temperature (°C)	16.2	22.4	18.8	12.3	-	-
rel.humidity (%)	61	50	65	60[3]	-	-
total ppt. (cm)	7.44	2.61	13.94	6.74	-	30.73

[1] from 12 June
[2] to 27 October
[3] to 13 September

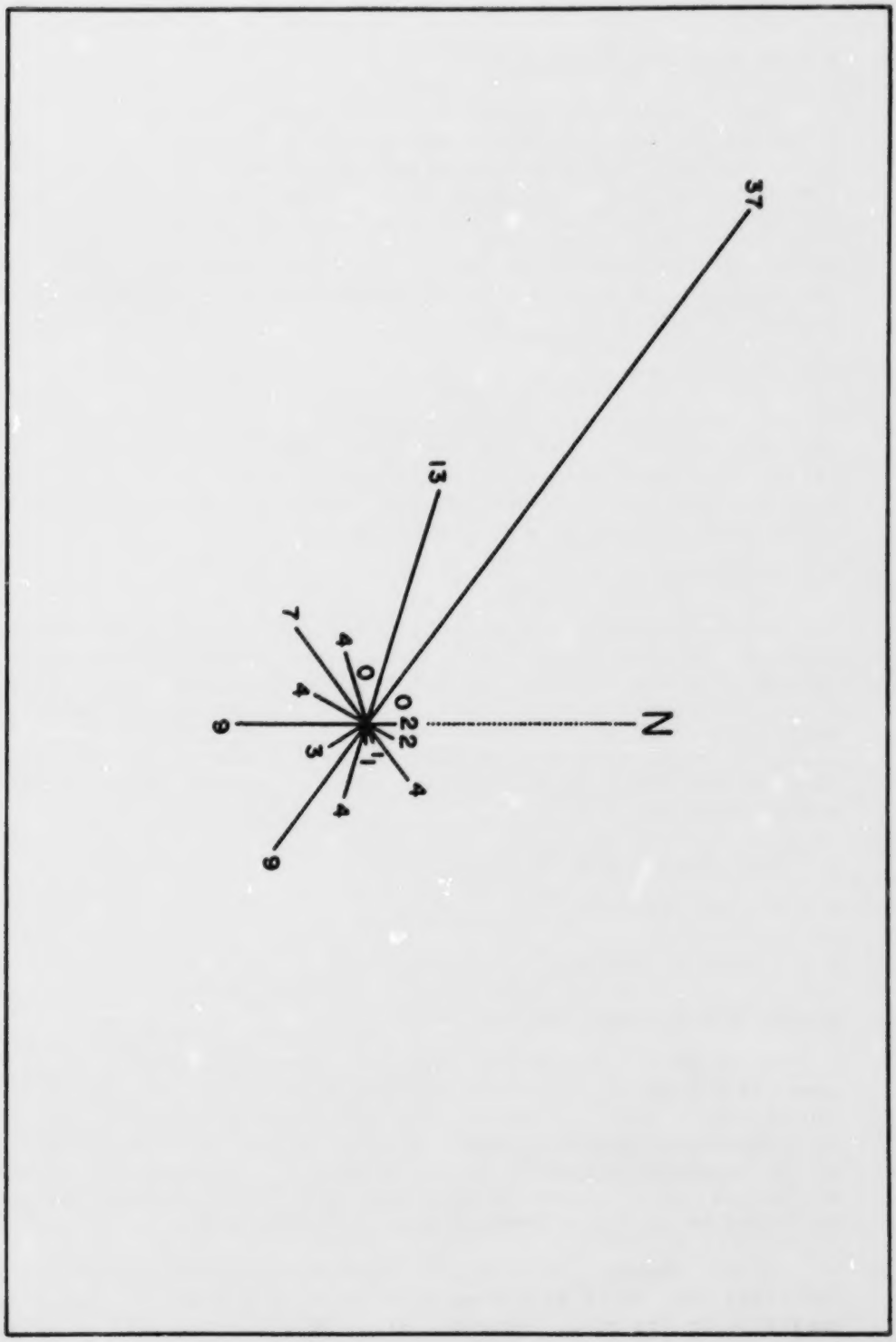

Figure 3: Radial diagram summarizing by the length of each ray the number of days (12 June - 13 September, 1985) that wind was from each respective direction. Numbers represent the directional totals as a percentage of the total observation period.

2.3 Mid-day Air Temperature

Air temperature (1300 CDT) increased with time in June (Figure 2C) and reached a maximum of 29.5°C on 7 July (day 188). Daily minima and maxima during this period were ca. 14 and 34°C respectively. In the next 4 week period, mean mid-day daily temperature was about 22°C (Table 1) and varied between 7 and 32°C. From mid August (day > 220), air temperature decreased until, on 8 October (day 291), the first temperature below 0°C was recorded. A short period of warmer weather occurred in mid-October (Figure 2C).

2.4 Relative Humidity

Relative humidity fluctuated widely on a daily basis but was generally greater than 50% throughout most of June (Figure 2D, Table 1). There was a slight decrease in humidity through July and an increase in mid-August due to the incidence of several heavy precipitation events (Figure 2E).

2.5 Daily Cumulative Precipitation

All precipitation received at the Pine Falls site during the study period was as rainfall. Individual daily receipts during June were generally less than 1cm (Figure 2E). Total precipitation in July was 2.61cm (Table 1) but increased significantly in August (ca. 45% of total received during period of observation - 30.73cm) owing to sustained heavy rainfalls over a period from 12-15 August (days 224-227). Heavy rains (>1cm/day) occurred on 6 and 22 September.

3.0 Study Pond Characterization

3.1 Physical Parameters

3.1.1 Pond Morphometry

Water Depth Fluctuations

Permanent water depth benchmarks were established in each pond to monitor fluctuations in pond water level through time. The stakes to which the benchmarks were attached were imbedded in the bottom sediments as deeply as possible to counteract effects of ice movement during the spring breakup. The positions of the benchmarks were related to permanent terrestrial markers placed on trunks of adjacent trees (Figures 4-9; Table 2).

Water depths were initially monitored from the mean level indicated on three stakes used in locating biological sampling apparatus in the ponds (Appendix B). Relative changes in water depth, as measured by decreases in depth from the time of stake placement, were correlated to the permanent depth benchmark stakes (positioned in late summer) using linear relationships (Table 2) established from data for which readings on both markers were available.

Table 2: Pondwater depth (cm) indicated on permanent water depth marker (Figures 4-9). Depth to sediment can be calculated by adding bottom distance to each reading. Data to 24 September were estimated from corresponding readings from temporary markers (Appendix B). - no data

Date (1985)	Pond					
	Spruce	Raspberry	Pine	Golden	Hike	Birch
23 May	85.9	71.3	81.8	88.7	91.5	94.5
18 June	-	69.8	74.9	80.3	85.0	82.5
24 June	76.9	68.4	71.4	76.9	82.5	78.2
2 July	77.9	69.9	73.4	78.9	84.5	77.8
10 July	74.9	66.6	65.6	70.6	79.1	71.9
16 July	73.0	64.0	57.9	62.7	76.7	66.4
23 July	69.9	59.8	48.3	54.0	72.7	60.8
29 July	67.2	55.5	38.9	45.4	68.0	55.1
31 July	-	-	36.4	42.4	-	-
1 August	-	-	-	-	67.3	53.0
5 August	66.9	53.9	31.2	37.8	65.0	51.5
12 August	66.0	52.2	24.3	31.4	64.5	47.6
19 August	78.8	71.3	65.5	63.8	83.7	69.0
20 August	79.0	72.1	-	-	-	-
21 August	-	-	66.9	64.7	-	-
22 August	-	-	-	-	84.5	70.7
26 August	77.9	69.8	69.2	66.6	85.0	73.0
2 Sept.	76.0	66.8	67.3	65.2	82.1	69.7
9 Sept.	76.1	69.2	70.0	68.2	81.7	69.1
10 Sept.	76.1	69.2	-	-	-	-
11 Sept.	-	-	69.7	67.8	-	-
12 Sept.	-	-	-	-	80.0	67.1
16 Sept.	74.7	68.2	68.4	67.8	79.3	66.4
24 Sept.	75.0	70.0	70.0	70.0	80.0	65.0
30 Sept.	75.0	70.4	72.2	72.8	80.6	65.0
1 Oct.	75.0	70.6	-	-	-	-
2 Oct.	-	-	72.0	73.2	-	-
3 Oct.	-	-	-	-	80.6	64.8
8 Oct.	75.5	71.2	73.0	75.8	81.4	65.2
15 Oct.	76.8	72.6	77.4	80.6	83.8	67.8
21 Oct.	76.9	67.9	77.3	81.3	84.5	69.3
22 Oct.	76.8	68.0	-	-	-	-
23 Oct.	-	-	77.6	82.4	-	-
24 Oct.	-	-	-	-	85.0	70.2
28 Oct.	77.2	67.8	77.0	82.2	85.0	69.8
12 Dec.	89.0	70.2	78.0	87.0	94.0	79.7
Distance (Sed.)	12.0	17.4	13.0	6.0	0.0	18.0
Corr.Coeff.	-0.984	-0.924	-0.994	-0.999	-0.997	-0.987
Ht. 100cm mark to terrestrial benchmark						
#1	174.5	122.2	125.8	141.6	163.7	145.7
#2	-	-	125.8	141.6	163.7	145.7

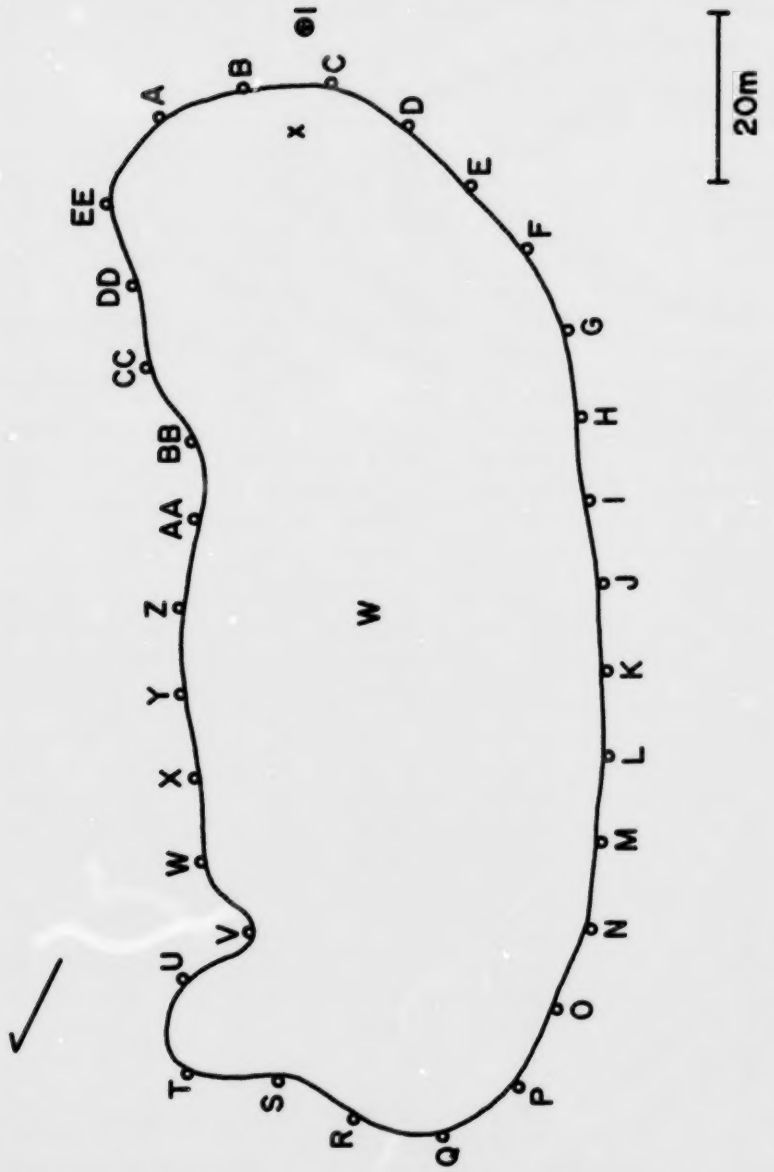

Figure 4: Reconstructed shoreline morphometry of Spruce Pond based on measurements between selected pairs of peripheral stakes A to EE (Appendix C). The location of each stake was established from its distance to two others using the cosine law. Also shown are the approximate locations of the permanent water depth benchmark (X), corroborative terrestrial benchmark (■) and water sampling station (W).

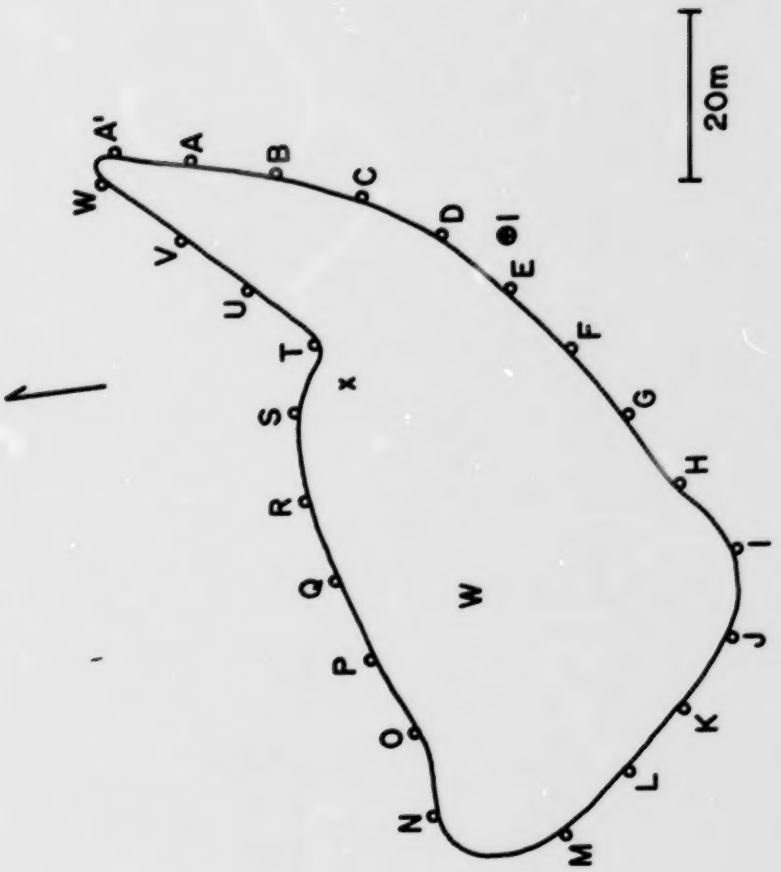

Figure 5: Reconstructed shoreline morphometry of Raspberry Pond based on measurements between selected pairs of peripheral stakes A to W (Appendix D). The location of each stake was established from its distance to two others using the cosine law. Also shown are the approximate locations of the permanent water depth benchmark (X), corroborative terrestrial benchmark (■) and water sampling station (W).

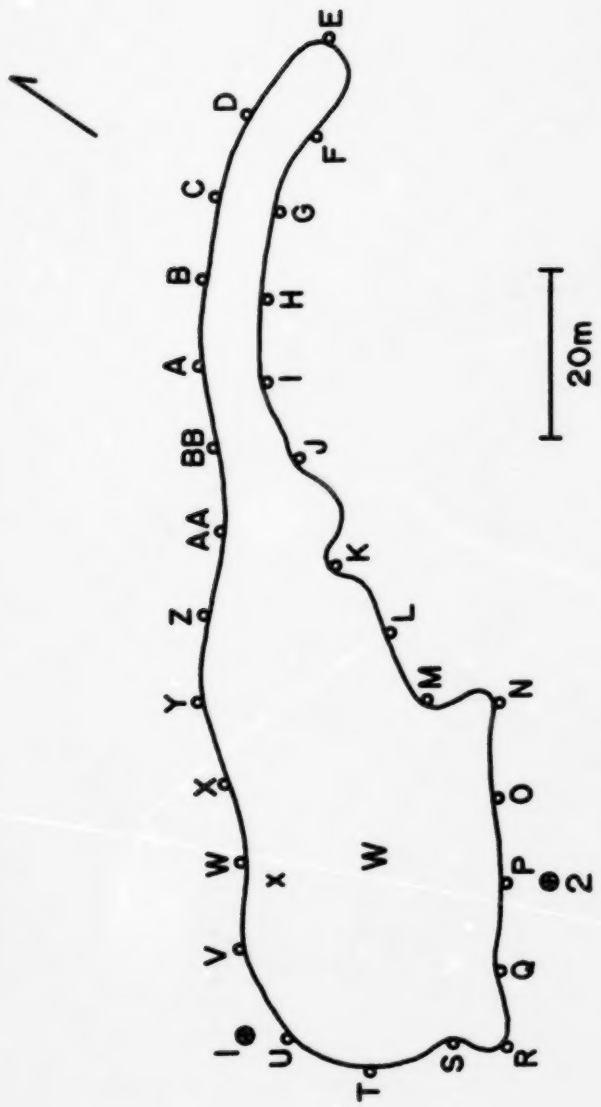

Figure 6: Reconstructed shoreline morphometry of Pine Pond based on measurements between selected pairs of peripheral stakes A to BB (Appendix E). The location of each stake was established from its distance to two others using the cosine law. Also shown are the approximate locations of the permanent water depth benchmark (X), corroborative terrestrial benchmark (■) and water sampling station (W).

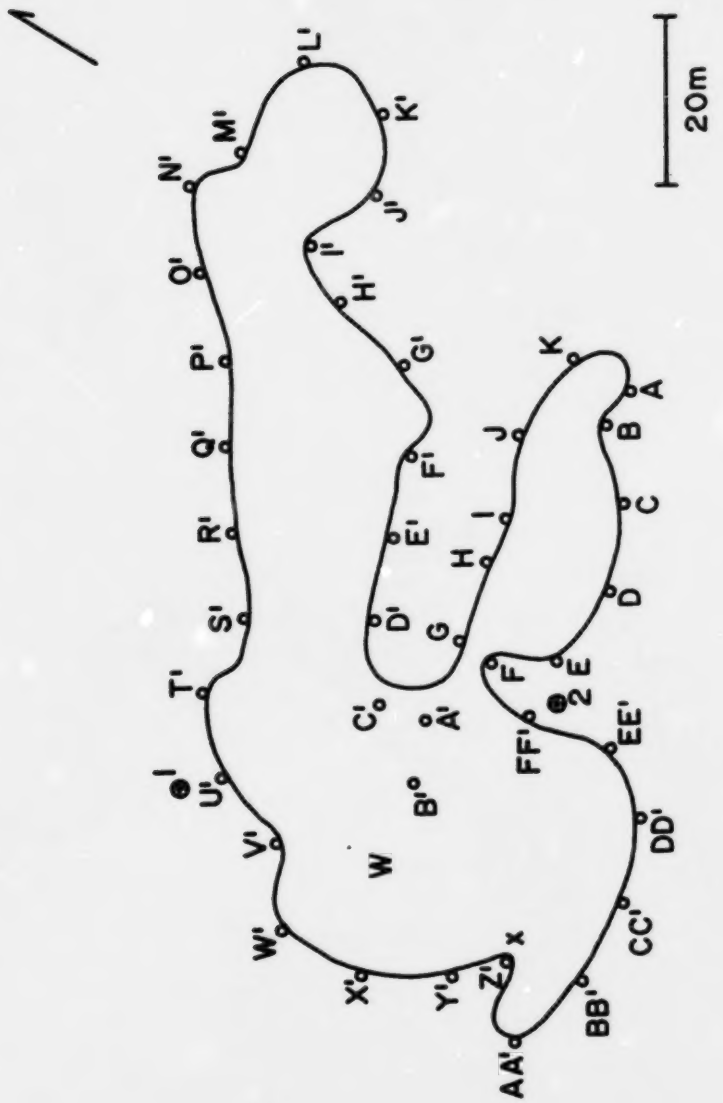

Figure 7: Reconstructed shoreline morphometry of Golden Pond based on measurements between selected pairs of peripheral stakes A to FF' (Appendix F). The location of each stake was established from its distance to two others using the cosine law. Also shown are the approximate locations of the permanent water depth benchmark (X), corroborative terrestrial benchmark (■) and water sampling station (W).

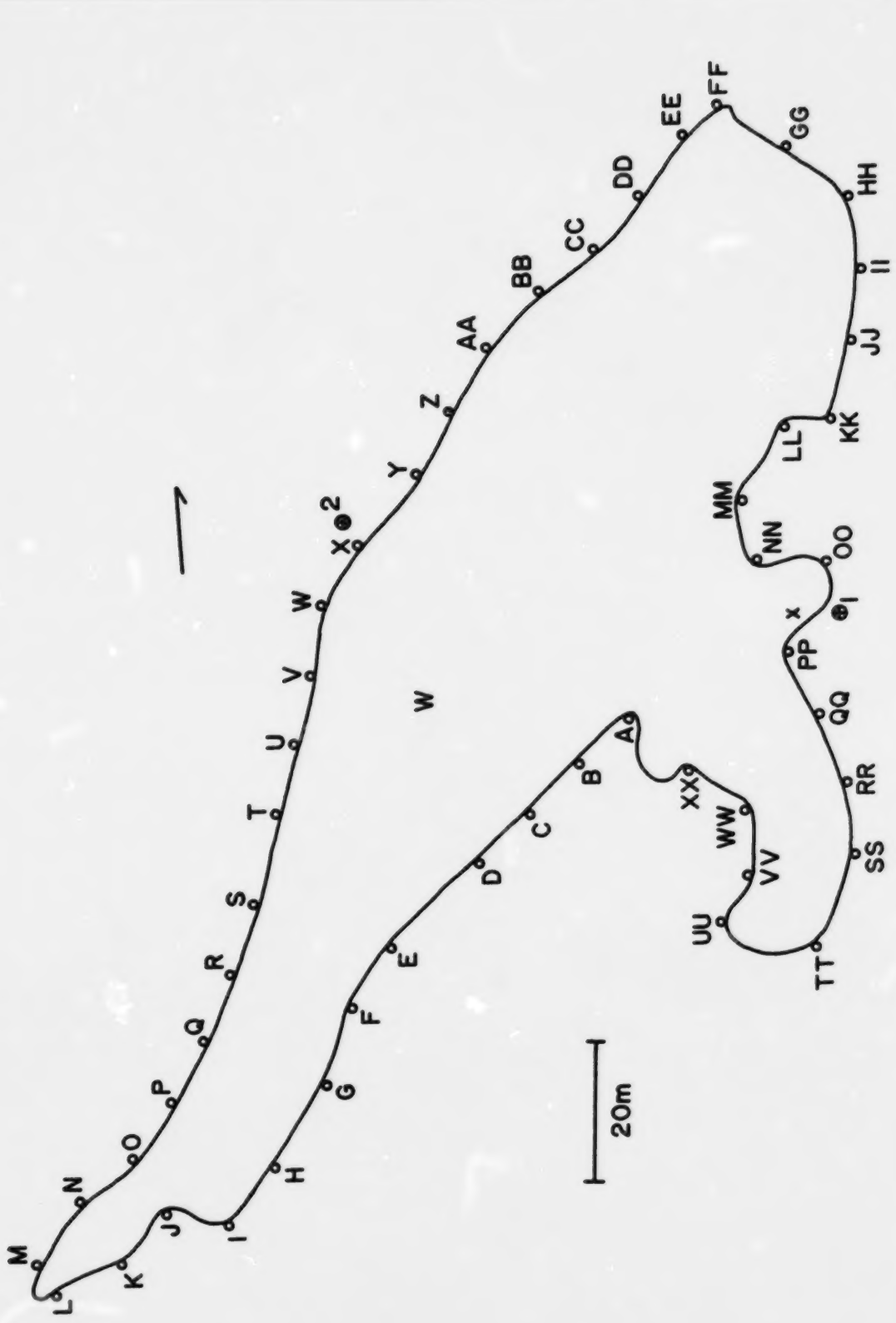

Figure 8: Reconstructed shoreline morphometry of Hike Pond based on measurements between selected pairs of peripheral stakes A to XX (Appendix G). The location of each stake was established from its distance to two others using the cosine law. Also shown are the approximate locations of the permanent water depth benchmark (X), corroborative terrestrial benchmark (■) and water sampling station (W).

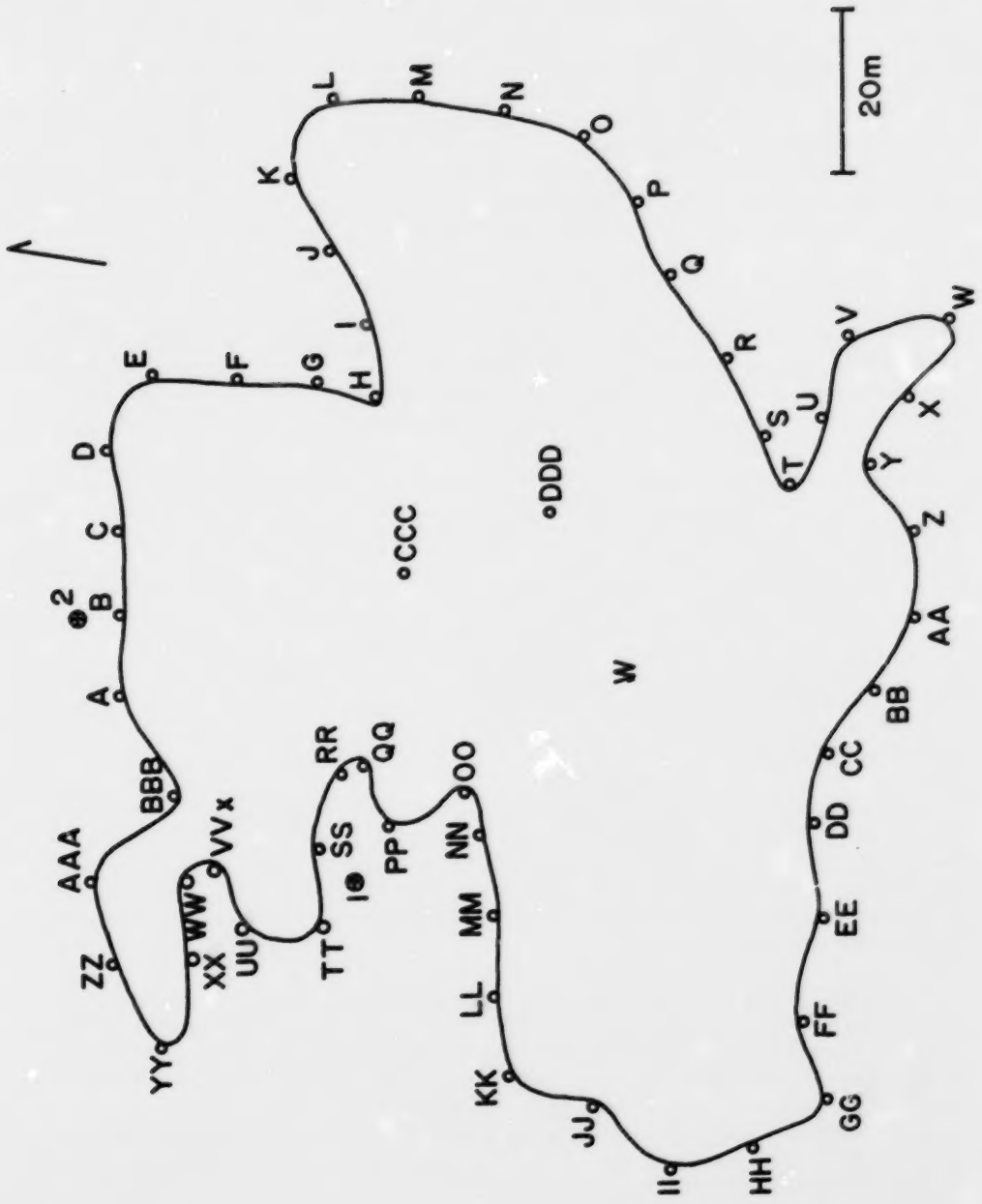

Figure 9: Reconstructed shoreline morphometry of Birch Pond based on measurements between selected pairs of peripheral stakes A to CCC (Appendix H). The location of each stake was established from its distance to two others using the cosine law. Also shown are the approximate locations of the permanent water depth benchmark (X), corroborative terrestrial benchmark (■) and water sampling station (W).

Water levels in all ponds (Figure 10) decreased between the beginning of the observation period (23 May) and the beginning of July (ca. day 180). The rate of loss later increased significantly, presumably as a result of reduced precipitation (Figure 2E), increased evaporation through higher temperatures (Figure 2A), lower relative humidity (Figure 2D), and transpiration losses by emergent macrophytes. The rates of loss were essentially linear ($r>0.9$) over a period of about 6 weeks: -0.3 cm/day (Spruce), -0.5 cm/day (Raspberry), -1.3 cm/day (Pine), -1.2 cm/day (Golden), -0.5 cm/day (Hike) and -0.8 cm/day (Birch).

Between 12 and 19 August (days 224-231), dramatic increases in the levels of all ponds (Figure 10) coincided with a receipt of 11.3cm of precipitation at the Pine Falls site (Figure 2E). The depth increases ranged from 12.8cm (Spruce) to 41.2cm (Pine), and in some cases recharged the ponds to a level similar to that of early July (Figure 10). The relative differences between areal receipt and increase in level reflects varying contributions of the drainage areas and groundwater recharge, although the magnitude of these factors is unknown since other contributing factors (eg. evapotranspiration losses) were not quantified.

Pond levels remained constant or increased slightly with time in September and October (Figure 10). Estimates of pond depth inferred from levels of ice on the permanent benchmark on 12 December (Table 2) suggest that the ponds continued to infill until freezeup (date not recorded).

Basin Morphology

Stakes were positioned around the shoreline of each pond (Figures 11-16) for determination of surface area. The distances between successive stakes was 10 metres except where irregular shoreline or absence of soil warranted alternate locations. These distances, as well as those of selected pairs of stakes, are tabulated in Appendices C-H.

Table 3 summarizes important morphometric characteristics of each pond. Temporal changes in depth (Figure 10) were implicit in these parameters because bathymetric measurements were conducted over a six-week period. To compare all ponds on a common basis, estimates of mean depth, maximum depth and pond volume on 16 July (the temporal midpoint) were extrapolated from differences in water depth at the respective markers in each pond. Because the ponds have steep banks (presumably as a result of their artificial origin), pond surface area was assumed to be constant through time except where changes in shoreline extent were observed and quantified (Appendices L and N). Despite these corrections, however, comparisons between the ponds were not altered (Table 3); the ponds vary in size with areas ranging from 1980 m^2 (Pine) to 7681 m^2 (Birch). The range in enclosed water volume shows a commensurate trend and all ponds are shallow (mean depth < 1.5 m, maximum depth $<$ ca. 4 metres). Volume development measurements (which compare pond volume to that of a cone with the same surface area and maximum depth) are similar between the

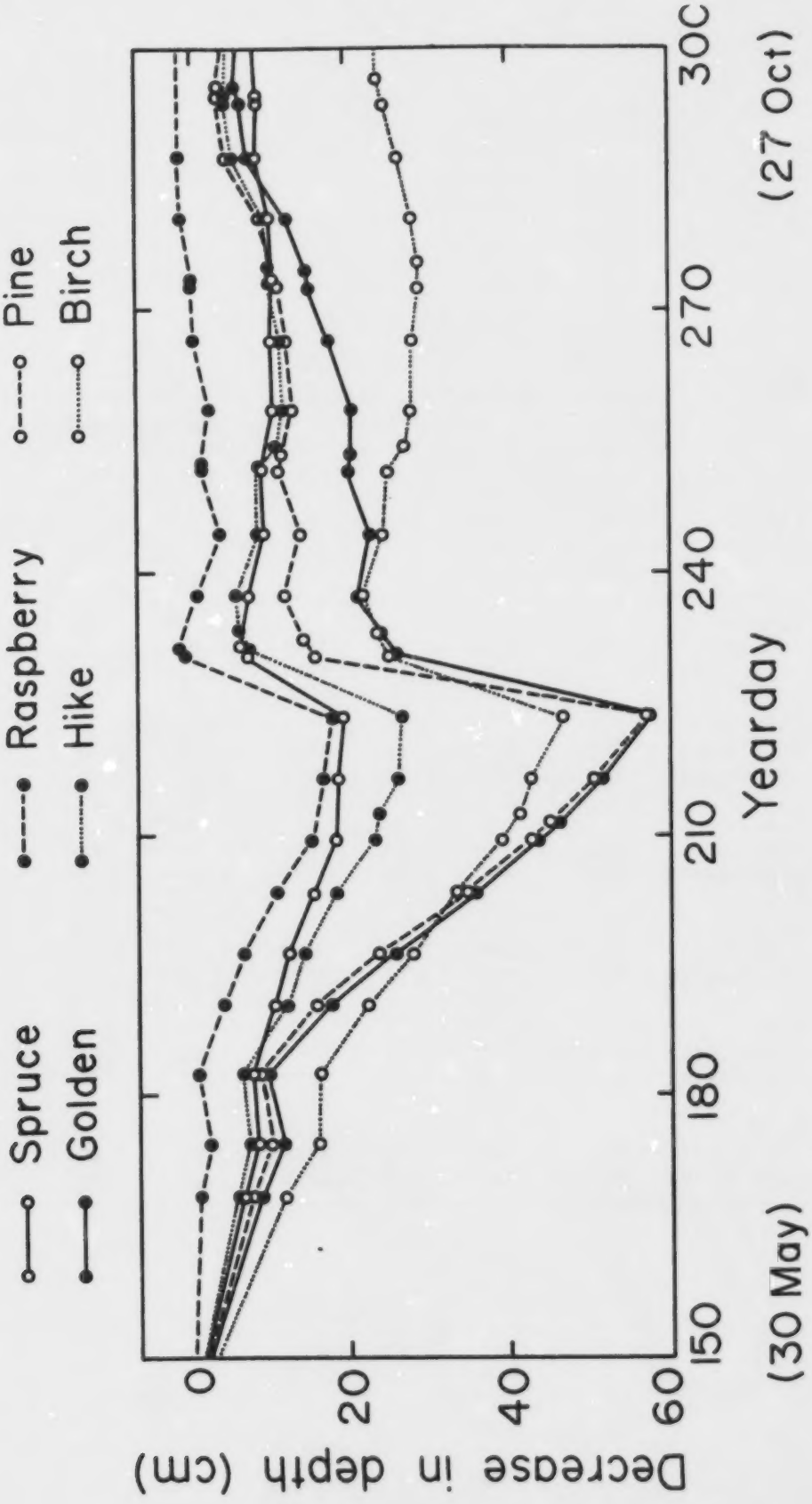

Figure 10: Change in pond water depth (23 May - 0cm) through the duration of the study period (1985).

Table 3: Summary of morphometric characteristics of the six experimental ponds (1985). D_L = Shoreline development, D_v = Volume development. Estimates of all parameters on a common depth basis (16 July, 1985) are also given.

Pond	Length Shoreline (m)	Area (m^2)	D_L	Volume (m^3)	Mean Depth (m)	Max Depth (m)	D_v
Spruce							
(9 July)	319	5168	1.25	7445	1.44	2.90	1.49
(estimate)	319	5168	1.25	7347	1.42	2.88	1.48
Raspberry							
(26 June)	246	2597	1.36	2491	0.96	1.95	1.48
(estimate)	246	2597	1.36	2374	0.91	1.91	1.43
Pine							
(25 July)	296	1980	1.88	1871	0.94	2.87	0.98
(estimate)	296	1980	1.88	2130	1.08	3.00	1.08
Golden							
(22 July)	414	2659	2.27	2508	0.94	3.08	0.92
(estimate)	410	2946	2.13	2802	0.95	3.18	0.90
Hike							
(7 August)	541	6325	1.92	8380	1.32	4.07	0.97
(estimate)	541	6325	1.92	9152	1.45	4.19	1.04
Birch							
(8 August)	559	7102	1.80	9983	1.41	3.80	1.11
(estimate)	536	7681	1.79	11389	1.48	3.98	1.12

six ponds, although are highest for the most northerly ponds (Spruce and Raspberry)(Table 3). Hypsographic (depth-area) and depth-volume profiles are presented in Figure 11.

Spruce Pond is contained within a kidney-shaped basin (Figure 12) gently sloping at the northern and southern ends with steeper banks along the long axis. The bottom of the basin is flat throughout except for a small depression in the northeastern corner. No sources of overland inflow or outflow to the pond were detected during field surveys.

The basin of Raspberry Pond is roughly square with a long narrow protrusion on the northeastern corner (Figure 5). The basin is subdivided into three sub-basins by a bottom ridge between stakes H and O, and laterally to stake T (Figure 13). Relative depth maxima were 1.85, 1.95 and 1.52 metres in the northern, southwestern and southeastern basins respectively (26 June). The latter basin slopes gently upwards into the northeastern extension, which borders on an adjacent pond (Pond C; Table 4B). During periods of high water, the adjacent pond provides some overland flow into Raspberry Pond along with drainage from a wetland near stake H. Inflow is compensated by irregular outflow near stake M.

Pine Pond is the smallest of all those surveyed (Figure 6), and consists of an elliptical main basin and a long extremely narrow protrusion extending northeastward (Figure 14). The two basins are largely separated in the pond center (between stakes L and Z) by a small island which is intermittently below the water surface. The pond is bordered by a small pond along the northwestern shore between stakes B and AA, although no surface connection exists.

Golden Pond (Figure 7) has two discrete basins separated by a shallow constriction between stakes F and G (which is above the water surface during periods of low water). The larger basin is generally flat within a circular area encompassed by stakes T' through X', although areas near stake CC' and stakes A' to C' extend above the water surface during high water. A depression near stake W' extends northeasterly in a gradual grade. The eastern shore is less steep than the western shore so that the shoreline recedes (Figure 15 - dotted contour line) as the water level in the pond decreases. The pond has no visible sources of overland inflow or outflow.

The basin of Hike Pond consists of a sub-basin in each of three areal extensions (Figure 16). Relative depth maxima in the northeastern, southeastern and southwestern basins were 3.32, 2.47 and 4.07 metres respectively (7 August, 1985). The southwestern basin is bordered on one side (stake E - Figure 8) by a bare rock outcrop and extends longitudinally in a narrow trench. It is separated from the northeastern basin by a flat area delimited by stakes A, X, Z and NN, small permanently exposed islands near stakes W and AA, and a shallow shelf adjacent to stakes BB through FF. The shelf gives way abruptly to the north-

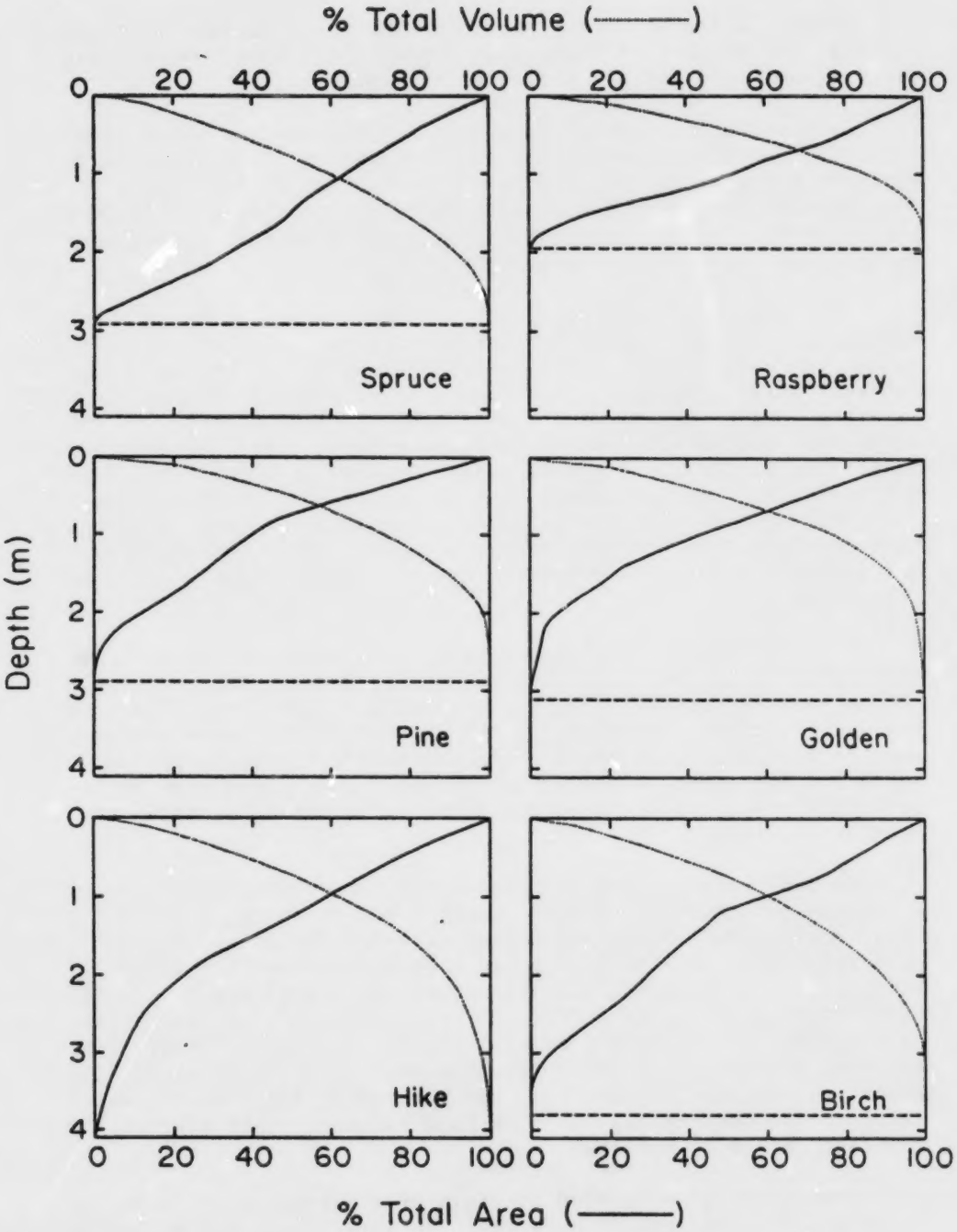

Figure 11: Hypsographic (solid line) and depth-volume (dotted line) profiles of each pond based on surface area digitization of pond depth strata (Figures 12-17; Appendices I-T). Maximum pond depth at the time of depth soundings is indicated by the horizontal dashed line.

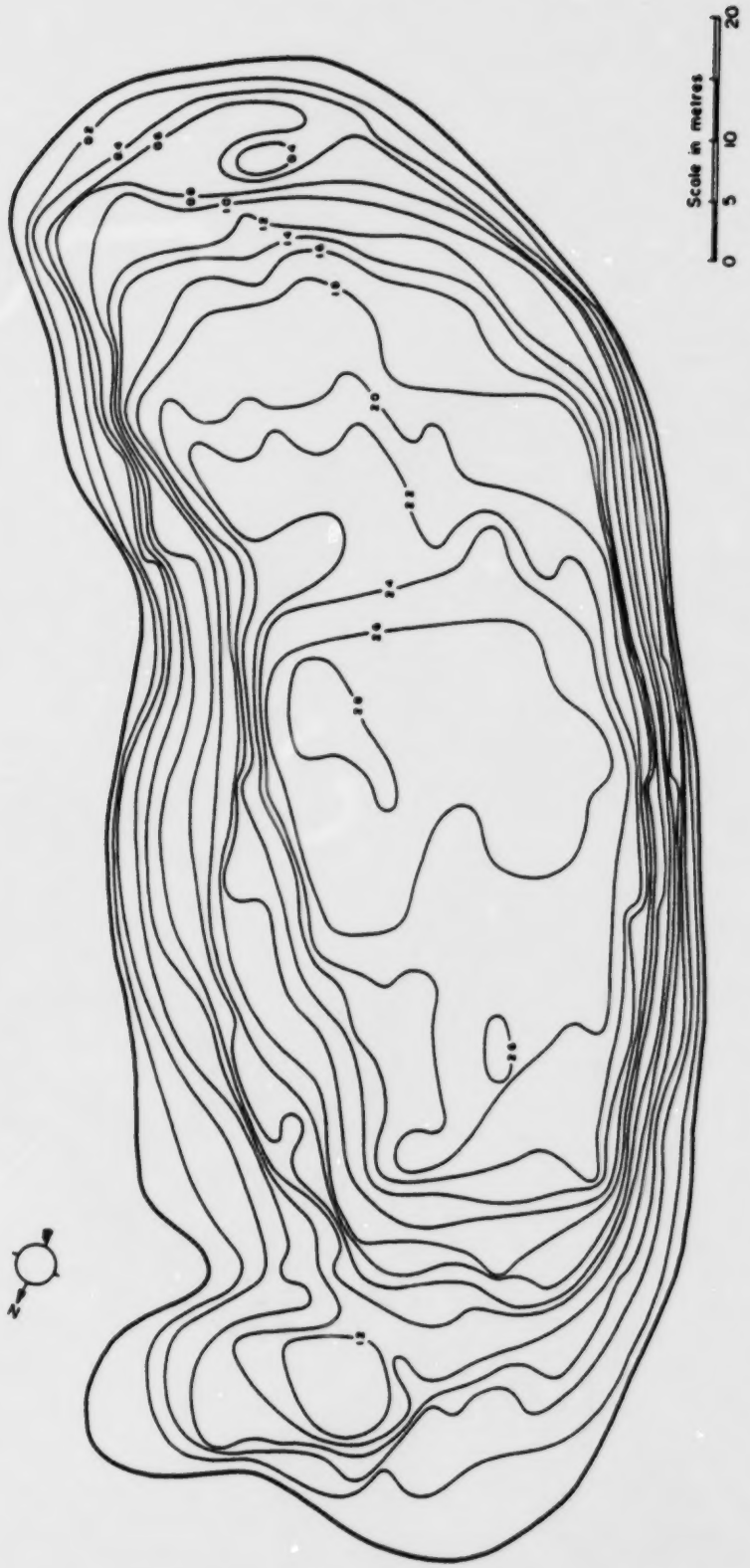

Figure 12: Bathymetric map (0.2 metre isobaths) of Spruce Pond generated from 497 soundings at 2.0 metre intervals along 26 lateral transects (9 July, 1985). Reference benchmark (Figure 4) depth at the time of sounding was 74.9 cm.

Figure 13: Bathymetric map (0.2 metre isobaths) of Raspberry Pond generated from 256 soundings at 2.0 metre intervals along 21 lateral transects (26 June, 1985). Reference benchmark (Figure 5) depth at the time of sounding was 68.5 cm.

Figure 14: Bathymetric map (0.2 metre isobaths) of Pine Pond generated from 225 soundings at 2.0 metre intervals along 27 lateral transects (25 July 1985). Reference benchmark (Figure 6) depth at the time of sounding was 44.8 cm. Dotted line is the observed shoreline at the time of sounding.

Figure 15: Bathymetric map (0.2 metre isobaths) of Golden Pond generated from 325 soundings at 2.0 metre intervals along 40 lateral transects (22 July, 1985). Reference benchmark (Figure 7) depth at the time of sounding was 52.7 cm. Dotted line is the observed shoreline at the time of sounding.

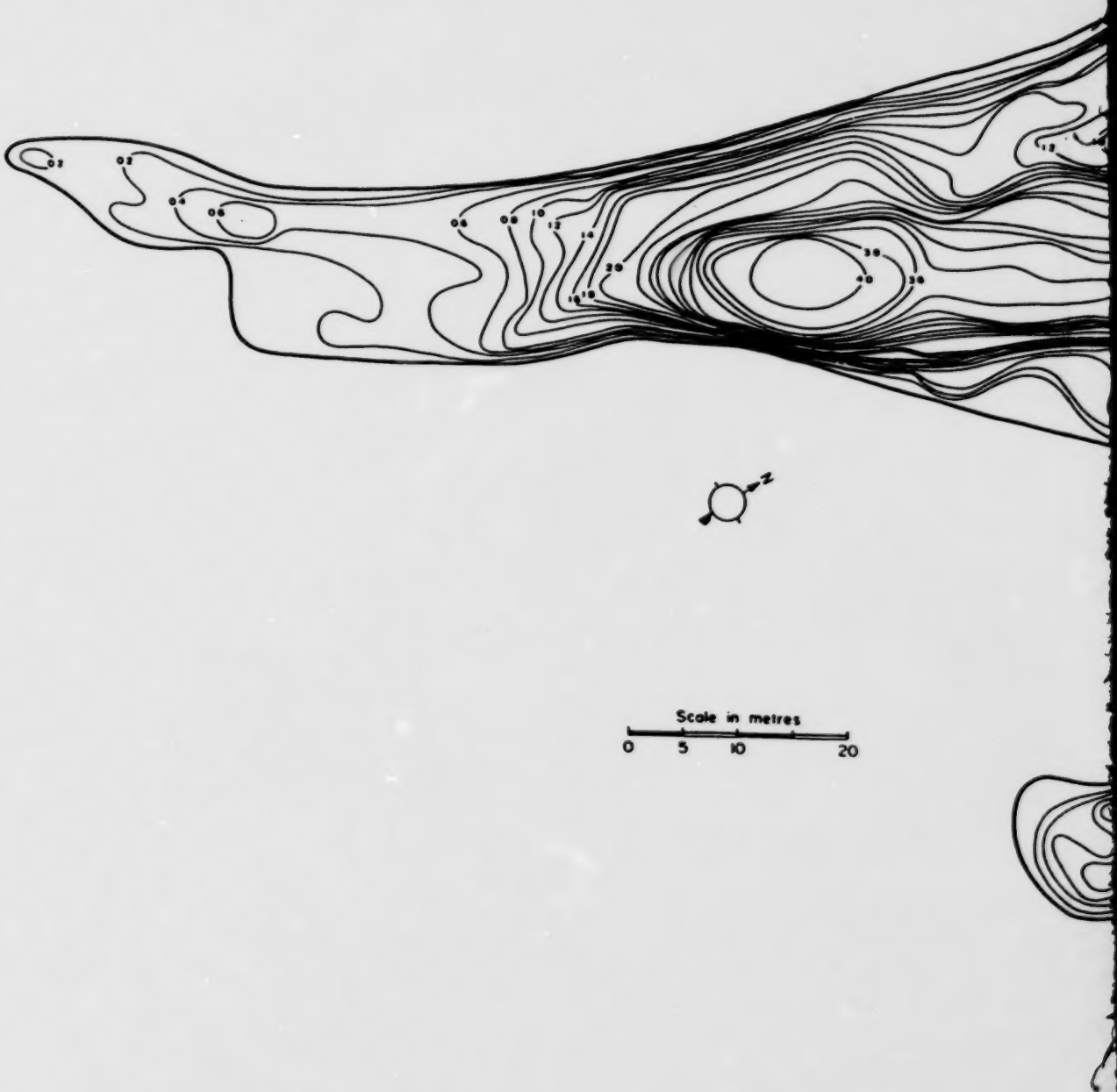

Figure 16: Bathymetric map (0.2 metre isobaths) of Hike Pond generated from 612 soundings at 2.0 metre intervals along 48 lateral transects (7 August, 1985). Reference benchmark (Figure 8) depth at the time of sounding was 64.5 cm.

eastern depression (Figure 16), which is bounded on the north-eastern shore by a rock outcrop. The shallow basin in the south-eastern protrusion leads to a gradual grade extending toward stake TT. No visible sources of overland water flow were found.

Birch Pond is the largest of the six chosen for this study (Table 3). To facilitate measurement of areal dimensions, marker stakes were established on each of two permanently exposed islands (CCC and DDD - Figure 9), which demark a shallow bay (water depth 0.6-1.2 m) on the northern side of the pond (delimited by stakes OO through O) from the deeper area to the south (Figure 17). Northwesterly protrusions from this bay, and a narrow offshoot along the south shore are shallow, and are either completely dry or reduced in areal extent during periods of low water. In contrast, the southern basin is steeply sloped (particularly along stakes O-T and KK-OO) and is bounded on the extreme south shore by a rock outcrop between stakes AA to FF. Deep trenchs on the western extent of the basin are separated by a ridge between stakes FF and LL (terminated by a permanently exposed island halfway across), and a depression on the eastern side is separated from a flat area near stake DDD by a small ridge offshore from stake S. There is no overland water inflow or outflow to the pond.

3.1.2 Water

Transparency

Light penetration of the water column (as indicated by Secchi disk depth) varied about 2 meters in the study ponds (Table 4). The waters of Spruce and Golden Ponds were generally clear and uncolored (Table 5) throughout the sampling period, to the extent that macrophytic populations colonizing bottom sediments were clearly visible. Short-term reductions in Secchi disk depth in these ponds (Table 4) usually resulted from wind-induced turbidity rather than phytoplankton blooms. In contrast, the waters of Raspberry and Pine Ponds were extremely colored (Table 5) so that Secchi disk depth was low (<1m). Moreover, light penetration decreased by 30-50cm over the duration of observations (Table 4) in response to a perceived increase in color--analytical limitations did not allow quantification of this trend. Birch Pond water was moderately colored and became more turbid in mid to late summer with a corresponding decrease in Secchi depth. Hike Pond, although relatively uncolored, had varying turbidity through much of the summer (Table 4).

Air/Water Temperature

Ambient air temperature above the pondwater surface was measured at the same time that water samples were collected. Although less exhaustive than data for the Pine Falls site (Figure 2C), similar seasonal trends were evident (Table 6). Differences between the respective ponds arose from temporal fluctuations occurring over the 1-3 hour mid-day period during which samples were collected and have no apparent systematic basis.

Figure 17: Bathymetric map (0.2 metre isobaths) of Birch Pond generated from 737 soundings at 2.0 metre intervals along 56 lateral transects (8 August, 1985). Reference benchmark (Figure 9) depth at the time of sounding was 48.1 cm. Dotted line is the observed shoreline at the time of sounding.

Table 4: Mid-day Secchi disk depth (m) measured in the center of study ponds (1985). () = greater than maximum water depth at sample site, . = no data). Asterisks denote statistics generated using one or more '>' datum.

Date	Pond					
	Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	.	0.75	1.33	1.68	1.40	1.50
23 May	.	.	.	.	.	.
11 June	2.84	0.78	1.30	>2.60	1.90	1.85
18 June	2.30	0.72	1.27	2.23	2.70	2.00
24 June	2.36	0.70	1.15	2.62	1.72	2.00
02 July	2.20	0.64	1.17	2.51	1.91	1.80
10 July	1.83	0.62	1.00	2.31	2.16	1.57
16 July	2.35	0.64	1.07	2.55	1.94	1.57
23 July	>2.76	0.62	1.07	>2.48	1.72	1.67
29 July	>2.80	0.76	0.88	>2.65	2.00	1.53
05 August	>2.72	0.72	0.93	2.07	1.82	1.64
12 August	>2.58	0.94	0.94	2.30	1.60	1.39
19 August	>2.76	0.69	1.03	2.60	1.35	1.00
26 August	>2.66	0.55	1.25	2.35	1.81	1.22
02 Sept.	>2.73	0.55	1.12	>2.84	2.09	1.42
09 Sept.	>2.58	0.43	0.95	>3.18	1.49	1.13
16 Sept.	>2.77	0.48	1.11	>3.00	1.95	1.16
24 Sept.	>2.82	0.51	0.79	2.59	1.95	1.14
30 Sept.	>2.81	0.50	0.71	2.68	2.03	1.17
08 Oct.	>2.65	0.47	0.75	2.53	1.75	1.03
15 Oct.	>2.62	0.53	0.79	.	2.00	1.22
21 Oct.	>2.69	0.52	0.75	2.06	1.87	1.04
28 Oct.	>2.69	0.43	0.86	1.82	2.09	0.99
12 Dec.	.	.	.	.	.	.
Minimum	1.83	0.43	0.71	1.68	1.35	0.99
Maximum	>2.82	0.94	1.33	>3.18	2.70	2.00
Median	>2.69	0.62	1.03	2.53	1.91	1.41
Mean	2.60*	0.62	1.01	2.46	1.88	1.41
StdDev(n-1)	0.25*	0.13	0.19	0.36	0.29	0.32

Table 5: True color (Platinum-cobalt units) of water collected from study ponds (1985). (. = no data, < = below detection limit, > = above detection limit). Asterisks denote statistics generated using one or more '>' datum.

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	20	>50	35	.	10	.
	01	20	.	.	.	.	.
23 May	02	15	>50	50	15	15	>50
11 June	03	15	>50	>50	15	15	>50
18 June	04	15	>50	>50	10	5	>50
24 June	05	15	>50	>50	5	5	>50
02 July	06	15	>50	>50	10	<5	>50
10 July	07	20	>50	>50	10	5	>50
16 July	08	15	>50	>50	15	<5	50
23 July	09	15	>50	>50	5	<5	50
29 July	10	15	>50	>50	5	<5	50
05 August	11	20	>50	>50	10	10	>50
12 August	12	15	>50	>50	5	5	>50
19 August	13	15	>50	>50	10	5	>50
26 August	14	15	>50	>50	10	5	40
02 Sept.	16	15	>50	>50	5	5	50
09 Sept.	17	15	>50	>50	10	5	>50
16 Sept.	18	15	>50	>50	5	5	>50
24 Sept.	19	20	>50	>50	15	10	>50
30 Sept.	20	15	>50	>50	15	10	>50
08 Oct.	21	15	>50	>50	15	10	>50
15 Oct.	22	15	>50	>50	10	15	>50
21 Oct.	23	15	>50	>50	15	15	>50
28 Oct.	24	15	>50	>50	20	10	>50
28 Oct.	25	15	>50	>50	15	15	>50
12 Dec.	26	20	>50	>50	15	10	>50
	26	15	.	.	.	.	.
Minimum		15	>50	35	5	<5	40
Maximum		20	>50	>50	20	15	>50
Median		15	>50	>50	10	5	>50
Mean		16	50*	49*	11	8	50*
StdDev(n-1)		2	0*	3*	4	4	2*

Table 6: Air temperature (°C) at time of water collection from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	10.0	10.0	10.0	17.0	15.0	17.0
.	01	10.0	.	.	.	.	.
23 May	02	25.0	25.0	14.0	14.0	.	.
11 June	03	18.0	18.0	15.0	15.0	15.0	15.0
18 June	04	18.5	17.0	18.5	18.5	20.0	21.0
24 June	05	22.0	20.0	20.0	20.0	20.0	20.0
02 July	06	21.0	23.0	26.0	26.0	26.0	27.0
10 July	07	20.0	21.0	19.0	21.5	22.0	20.0
16 July	08	21.0	22.0	22.5	24.5	25.5	26.0
23 July	09	24.5	24.0	26.0	26.0	24.0	24.0
29 July	10	25.0	25.5	26.0	25.0	26.0	25.0
05 August	11	23.5	24.5	27.0	27.0	26.0	26.0
12 August	12	16.5	15.0	15.0	17.0	16.5	16.5
19 August	13	.	.	.	.	.	.
26 August	14	24.0	23.0	26.0	27.0	25.0	25.0
02 Sept.	16	14.0	16.0	16.0	15.0	16.0	16.0
09 Sept.	17	16.5	14.0	14.0	15.0	14.5	14.5
16 Sept.	18	17.0	18.0	16.0	19.0	19.0	20.0
24 Sept.	19	8.0	8.5	8.5	8.5	8.5	8.0
30 Sept.	20	10.0	10.0	9.0	10.5	10.0	10.0
08 Oct.	21	1.0	1.0	1.5	1.0	1.5	1.0
15 Oct.	22	1.5	1.5	3.0	1.5	1.5	1.5
21 Oct.	23	20.0	19.5	19.5	18.0	18.0	16.0
28 Oct.	24	12.0	13.0	13.5	14.0	13.0	12.0
28 Oct.	25	.	.	.	.	.	.
12 Dec.	26	.	.	.	.	.	.

Surface water temperature also varied seasonally (Table 7), although inter-pond differences seldom exceeded 1.0°C. Maximum observed water temperature (23-25°C) occurred in early July, and decreased to 4.0°C by late September as corresponding air temperature minima fell below zero (Figure 2C). Thin surface ice crusts were occasionally observed in the early morning during this period. The short interval of warmer weather in mid October was reflected in a subsequent increase in surface water temperature. The date of final fall freezeup was not recorded.

3.1.3 Sediment

Description and Texture

Following digestion of organic matter from sediment samples with 30% H_2O_2, the remaining inorganic residue was divided into particulate size classes. The sand fraction (>0.05mm diameter) was separated via successive washings through a No. 270 mesh sieve (and subdivided by size where warranted by high relative proportions), while the silt (0.002-0.05mm diameter) and clay (<0.002mm diameter) fractions were separated using the pipette method (Kilmer & Alexander 1949). Sediment texture (particles < 2mm diameter) was determined from the relative gravimetric proportions of each class according to the Canadian System of Soil Classification (C.S.S.C. 1977). References to the clay fraction imply a specific particle size and not a clay mineral. Data are tabulated in Appendices U-BB and are summarized below.

Twelve surficial (ca. 0-10cm depth) sediment samples were collected from Spruce Pond (Figure 18). Two samples (1 and 11) were collected at sites within dense stands of the emergent macrophyte Typha spp. (water depth < 1m; Table 8), while site 2 was located within a small depression on the northern end of the pond (Figure 12). Samples 3, 6-9 and 11-12 were collected around the pond periphery at depths ranging from 1.56 to 2.31m. Three samples (4-5,10) were collected from the flat central portion of the basin (Figure 12).

Samples collected from the edges of Spruce Pond consisted largely of loose black gyttya underlain by gray/beige clay-like material, while samples from the center of the pond contained smaller proportions of gyttya, were mostly gray-colored and were structurally blocky. There was little spatial variability in sediment texture, with the clay content of all samples exceeding 70% (Figure 18). Silt comprised 13-23% of the remainder, while sand fractions consistently contributed <7% (Figure 18). All samples were classified as clays (Figure 24).

Nine sediment samples were collected from Raspberry Pond (Figure 19). Collection sites were chosen to include two samples (1 and 2) from the southwestern basin depression (Figure 13; Table 8), two (4,5) from the northern sub-basin and two (7,8) from the southeastern depression. Sample 3 was collected from the subsurface ridge between stakes O and H (Figure 5), while sample 6 was collected from the northeastern extension of the ridge in

Table 7: Surface water temperature (°C) of study ponds (1985).
(. = no data, < = below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	.	.	.	.	.	.
23 May	02	16.0	15.0	.	15.0	.	.
11 June	03	16.5	16.5	17.5	19.0	18.0	18.5
18 June	04	17.0	17.0	16.5	18.0	18.0	18.5
24 June	05	17.5	19.0	18.0	20.0	20.5	21.5
02 July	06	20.5	21.0	22.0	23.0	22.5	21.5
10 July	07	20.0	20.0	20.5	22.0	21.0	22.0
16 July	08	19.0	19.5	20.0	21.0	20.0	21.5
23 July	09	22.0	23.5	22.5	23.0	22.5	23.5
29 July	10	23.0	25.0	24.0	23.5	23.0	25.0
05 August	11	17.0	15.5	15.5	15.5	17.0	17.0
12 August	12	.	.	.	.	.	.
19 August	13	18.0	18.5	18.5	20.0	19.0	19.5
26 August	14	16.0	14.0	14.0	16.0	16.0	15.5
02 Sept.	16	13.5	13.5	13.0	13.5	14.0	13.5
09 Sept.	17	15.0	15.0	15.0	15.0	15.0	16.0
16 Sept.	18	9.0	8.0	9.0	9.5	9.5	9.0
24 Sept.	19	8.0	8.0	8.5	9.0	9.0	9.0
30 Sept.	20	4.0	4.0	4.0	4.0	4.5	4.0
08 Oct.	21	4.0	4.0	4.0	4.5	4.0	4.0
15 Oct.	22	6.0	7.5	8.0	8.0	7.5	7.5
21 Oct.	23	5.5	4.5	5.0	5.5	5.5	6.0
28 Oct.	24	5.5	4.5	5.0	5.5	5.5	6.0
12 Dec.	26	.	.	.	.	.	.

Table 8: Water depth (m) at sediment sampling sites in study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	0.72	1.44	0.65	0.25	1.68	1.08
2	1.03	2.00	1.02	1.54	4.21	1.06
3	2.31	1.20	1.48	1.41	3.63	1.05
4	2.71	1.56	1.34	1.97	1.84	0.81
5	2.54	1.48	2.05	1.49	2.16	0.96
6	1.96	0.24	1.72	3.09	0.57	2.53
7	1.77	1.36	2.57	1.42	1.91	3.00
8	2.28	1.25	2.14	1.00	1.56	2.41
9	1.90	0.28		1.08	1.16	2.63
10	2.68			0.85	2.42	1.87
11	1.00				1.29	3.13
12	1.56				1.01	2.80
13						3.27

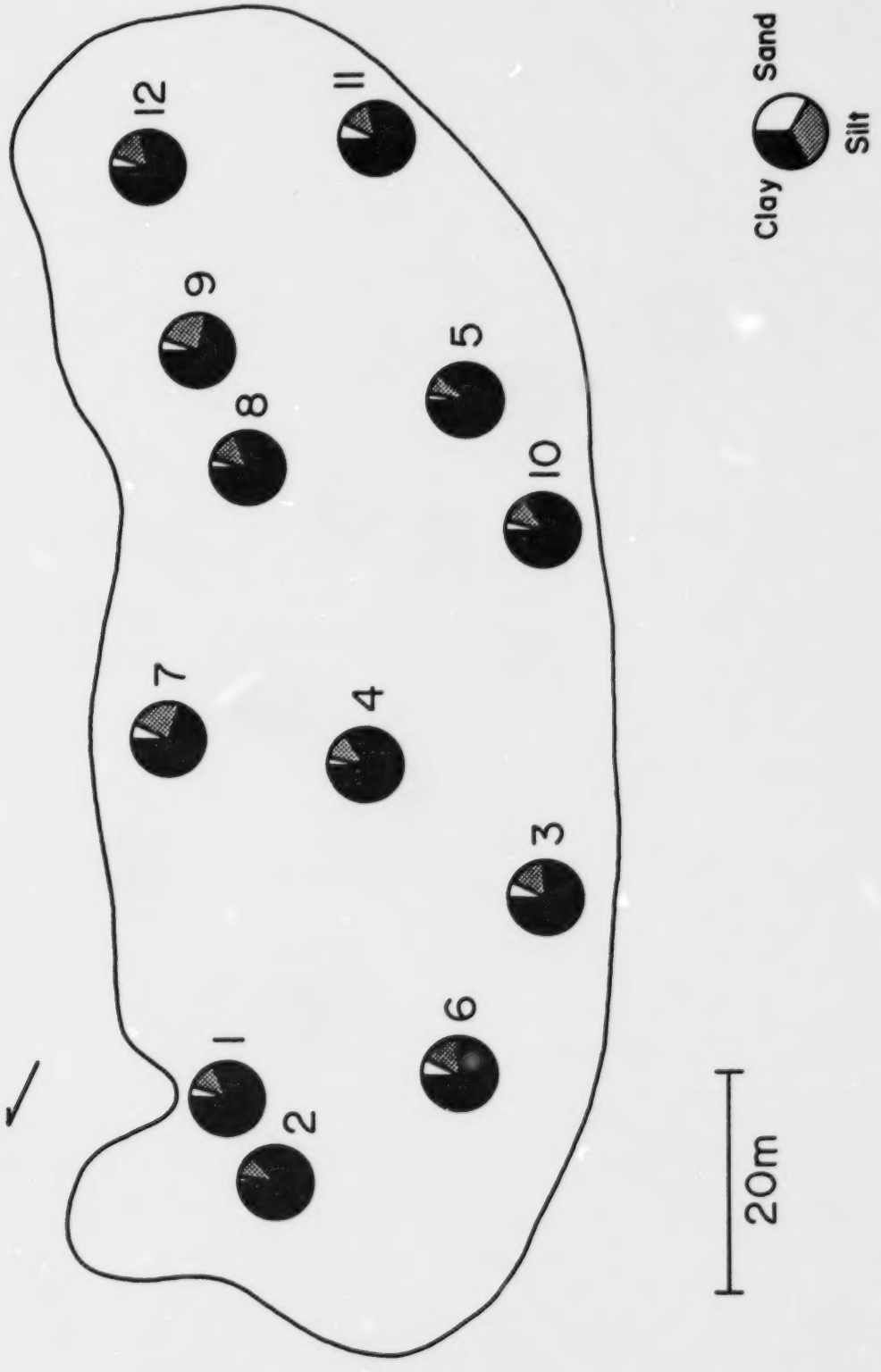

Figure 18: Location and inorganic texture of sediment samples collected from twelve sites in Spruce Pond (25 September, 1985)(Appendices U-BB).

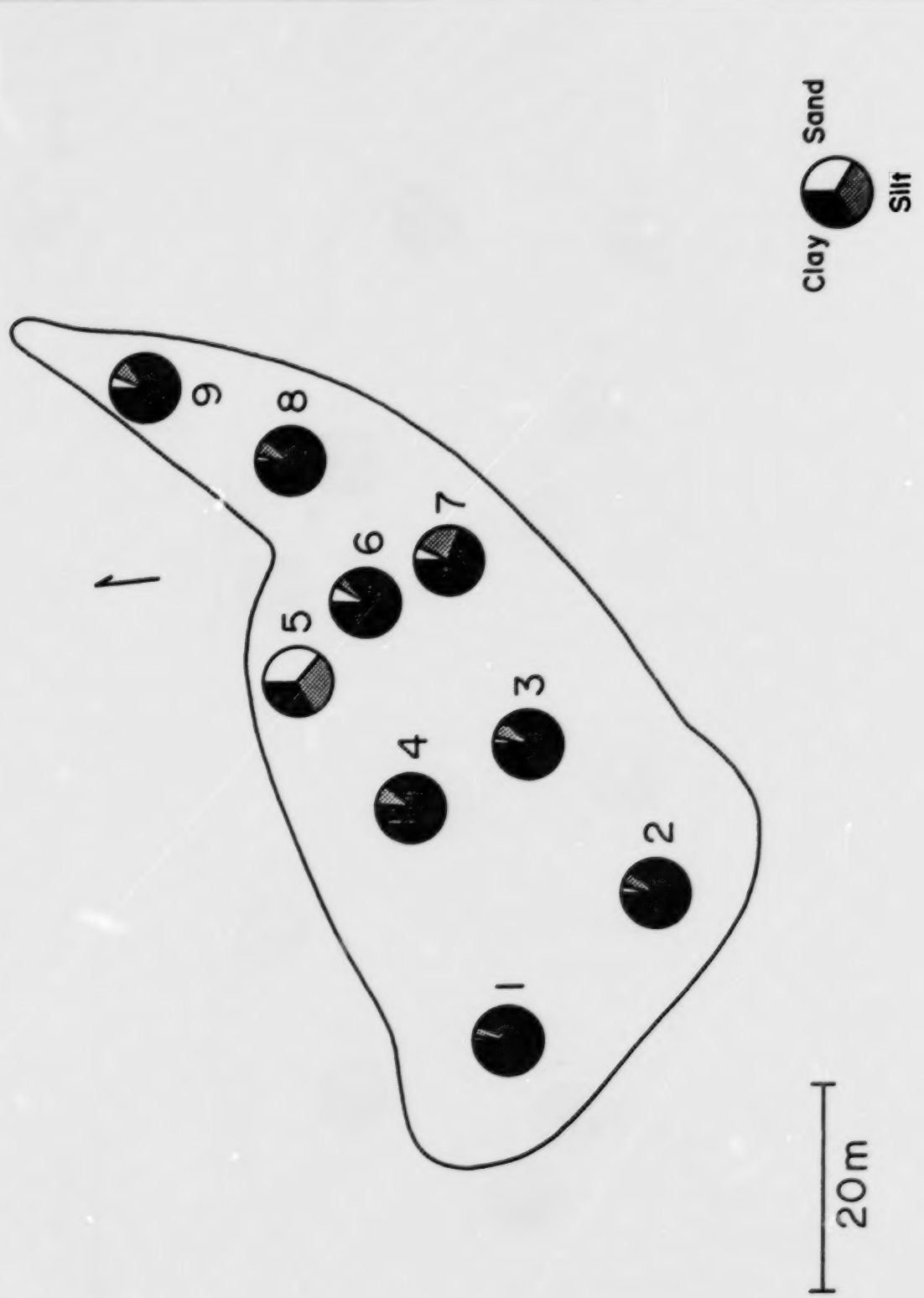

Figure 19: Location and inorganic texture of sediment samples collected from nine sites in Raspberry Pond (25 September, 1985)(Appendices U-BB).

shallow water among a stand of Typha spp. Sample 9 was also collected in shallow water (Table 8) among sparse Typha spp. growth.

All Raspberry samples except for number 6 were gray/black in color and contained a thin surficial layer of loose black gyttya. Sample 6 was brownish throughout. Samples 2, 4-5 and 8-9 were made up of gray/blue flakes and blocks. Texturally, all but one sample were high in clay (>88%; Figure 19) and silt (5-11%). Sample 5 was dissimilar to all others in that it contained about equal quantities of sand, silt and clay and corresponded to a clay loam (Figure 24).

Three samples (1-3) were collected from the narrow northeastern protrusion of Pine Pond (Figure 20) in progressively deeper water (Table 8). Five others were collected from randomly selected sites within the main basin. All samples were generally fluid, brownish green in color and contained large quantities of organic litter (tree leaves, twigs etc.) and detritus. Samples 3-8 were somewhat firmer than others and contained clay and/or sand lumps below the loose overlying layer.

The inorganic residues of all Pine Pond samples were loams (Figure 20). However, some degree of spatial variability was evident (Figure 20); samples 2-4 and 8 along the northwestern pond shore contained 38-56% sand, whereas samples 1,5 and 7 contained less sand and proportionately more clay. Except for sample 6, which was high in sand, silt content was similar in all samples (36-54%).

Ten sediment samples were collected from Golden Pond (Figure 21). Sample 1 was collected from shallow water among a dense bed of Equisetum sp. while sample 2 was collected from the center of the semi-detached eastern sub-basin. Four sample sites (3-6) were located within the deepest portion of the pond (Figure 21; Table 8), while sample 7-10 were collected sequentially along a trench extending northeastward. Sample 10 was collected from a shallow gravelly bay at the northern extent of the pond. Samples 1 and 10 consisted largely of loose gravel and pebbles, with little overlying detritus. All other samples were rich green/brown in color and were generally fluid. Samples 5 and 6 contained some hard gray clay lumps.

Samples from the central portions of Golden Pond were generally similar to each other (Figure 21) and contained quantities of silt ranging from 35-50%. The remainder was made up largely of sand, with clay contributing ca. 15%. These samples all classify as forms of loam (Figure 24). Samples from the pond periphery (1,10,4,5) contained more sand and less silt and clay, and were sands or loamy sands.

The locations of the twelve samples collected from Hike Pond were selected to include four sites (1-3,10) from the deep trench (Figure 16) running along the long axis of the pond (ranging in water depth from 1.68 to 4.21m--Table 8), two samples (4,5) from along the northwestern shore between two small islands, one sample

Figure 20: Location and inorganic texture of sediment samples collected from eight sites in Pine Pond (26 September, 1985)(Appendices U-BB).

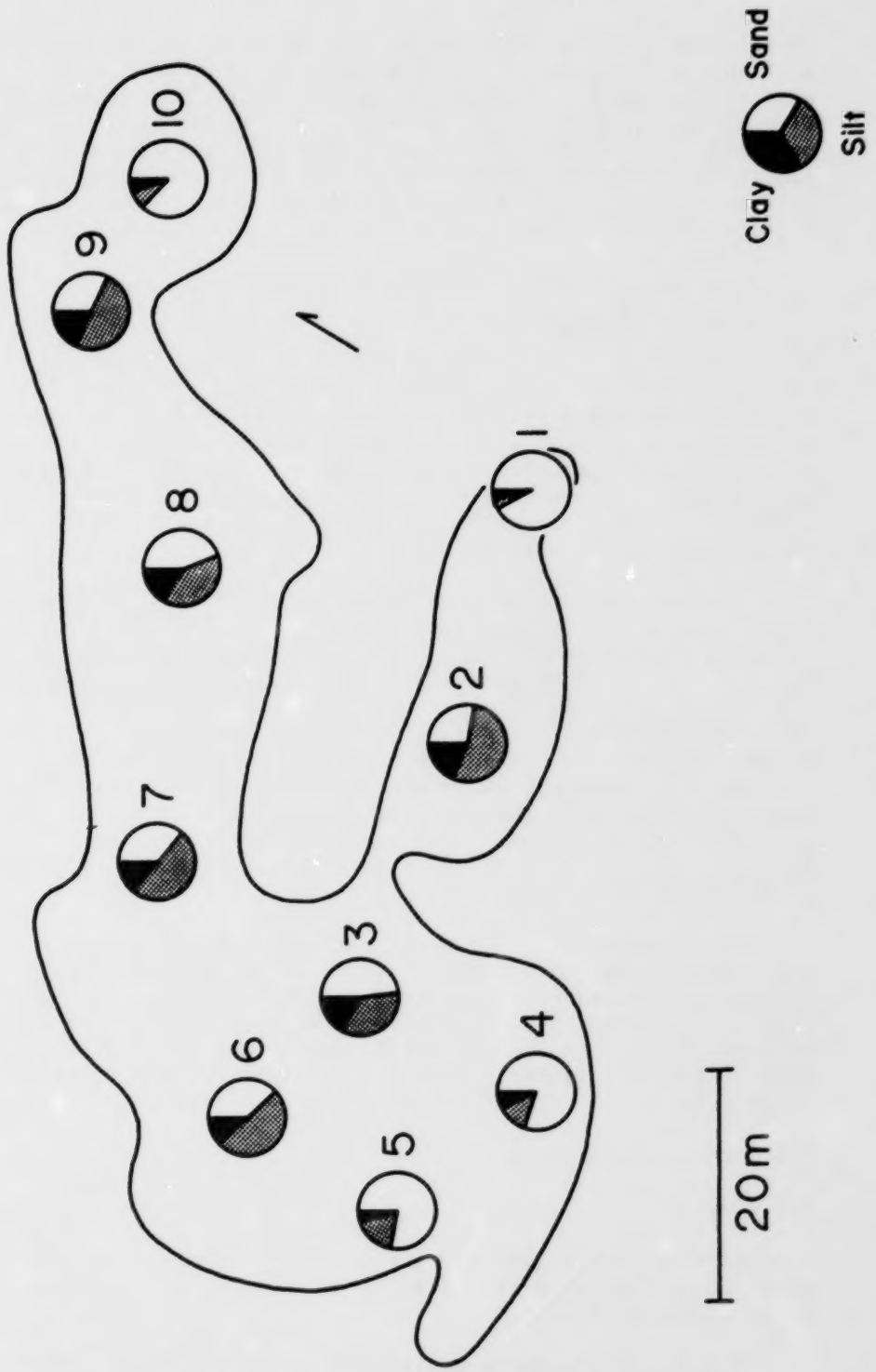

Figure 21: Location and inorganic texture of sediment samples collected from ten sites in Golden Pond (26 September, 1985)(Appendices U-BB).

(No.6) from the shallow shelf on the northeast of the pond among a stand of Typha spp., two samples (7-8) from within the northeastern depression, and three samples (9,11-12) extending laterally along the southeastern pond protrusion. The samples were all generally gray/brown in color with some overlying brown detritus. Sample 8 contained a small quantity of fluid, green-colored gyttya amongst the litter. Samples 2-4 and 11 also contained visible portions of sand under grayish, firm material.

Samples 1 and 2 from Hike Pond were both sandy clay loams (Figure 24) and consisted of about 50% sand, with the remainder made up nearly evenly by silt and clay (Figure 22). Samples from the deeper portions of the pond (3-4,8,10) contained high sand (56-64%) and low clay (10-14%) percentages although the silt fraction remained constant (ca. 25%). Samples from the center of the long axis (5,9) contained equal proportions of all three fractions, while samples 7 and 12 were mostly silt. A sample from the gravelly subsurface shelf (6) consisted primarily of sand (>80%), although a sample collected at the mouth of the southeastern protrusion was also sand-rich.

Sediment samples were collected from thirteen sites in Birch Pond (Figure 23) ranging in depth from 0.96-3.27m (Table 8). Three samples were collected from the shallow (ca. 1m) northern bay of the pond (Figure 17). These samples consisted almost entirely of fluid black/green/brown gyttya. Samples 4-6, collected from the northeastern portion of the pond, were similar in appearance, although the site 6 sample was qualitatively firmer. The remaining samples, which were collected from sites within the deeper (>2m) central and southwestern portions of the pond, were generally more brownish and contained an underlying layer of sand. This was most striking in sample 11, which was largely made up of coarse white sand.

Silt comprised ca. 50% of samples from along the southern and northern (except for No.2) sides of Birch Pond (Figure 23). Sand and clay were in nearly even proportion. On the other hand, sand constituted >50% of samples from around the central pond islands and at site 2. The site 11 sample was a sand (>87% coarse sand). With this latter exception, all samples were forms of loam (Figure 24).

3.2 Chemical Parameters

3.2.1 Water

Surface water samples were collected from a fixed point in each pond (Figures 4-9). Results of chemical analyses are compiled in Tables 9-32.

Means and standards deviations in tabulated data which are flagged with an asterisk have been calculated with at least one "less than" (<) and/or "greater than" (>) value. These values are entered into the calculation as the numerical equivalent to the reported value. Parameter values are qualified by "<" or ">" when

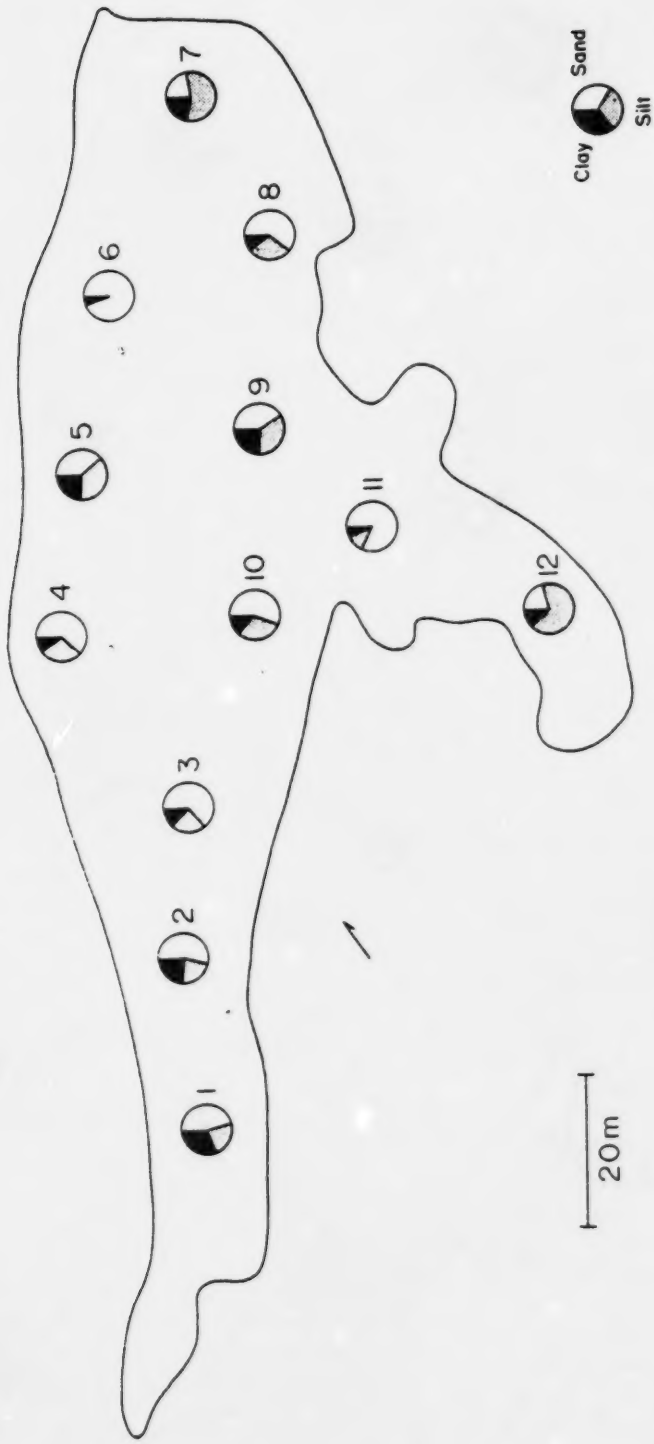

Figure 22: Location and inorganic texture of sediment samples collected from twelve sites in Hike Pond (26 September, 1985)(Appendices U-BB).

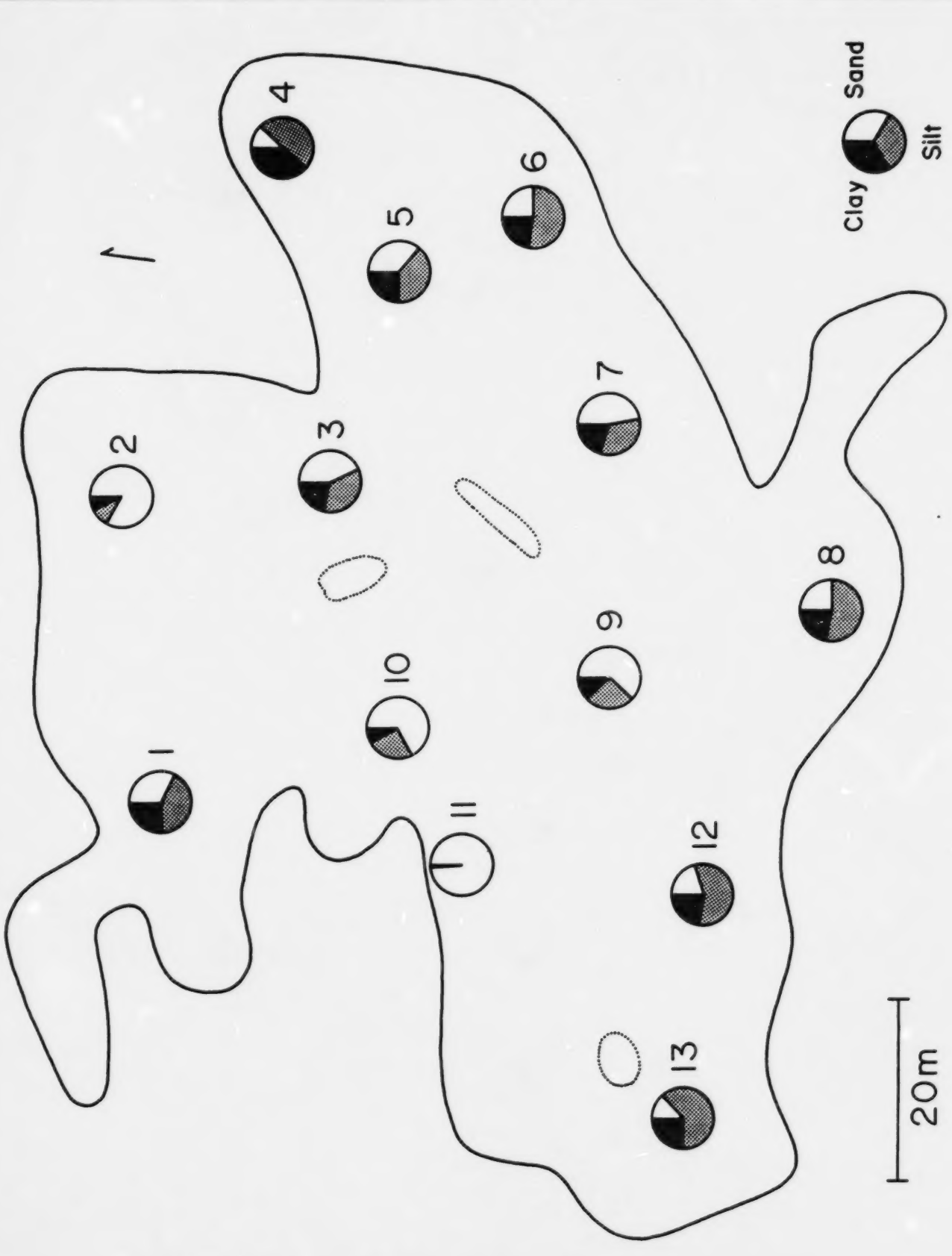

Figure 23: Location and inorganic texture of sediment samples collected from thirteen sites in Birch Pond (25 September, 1985)(Appendices U-BB).

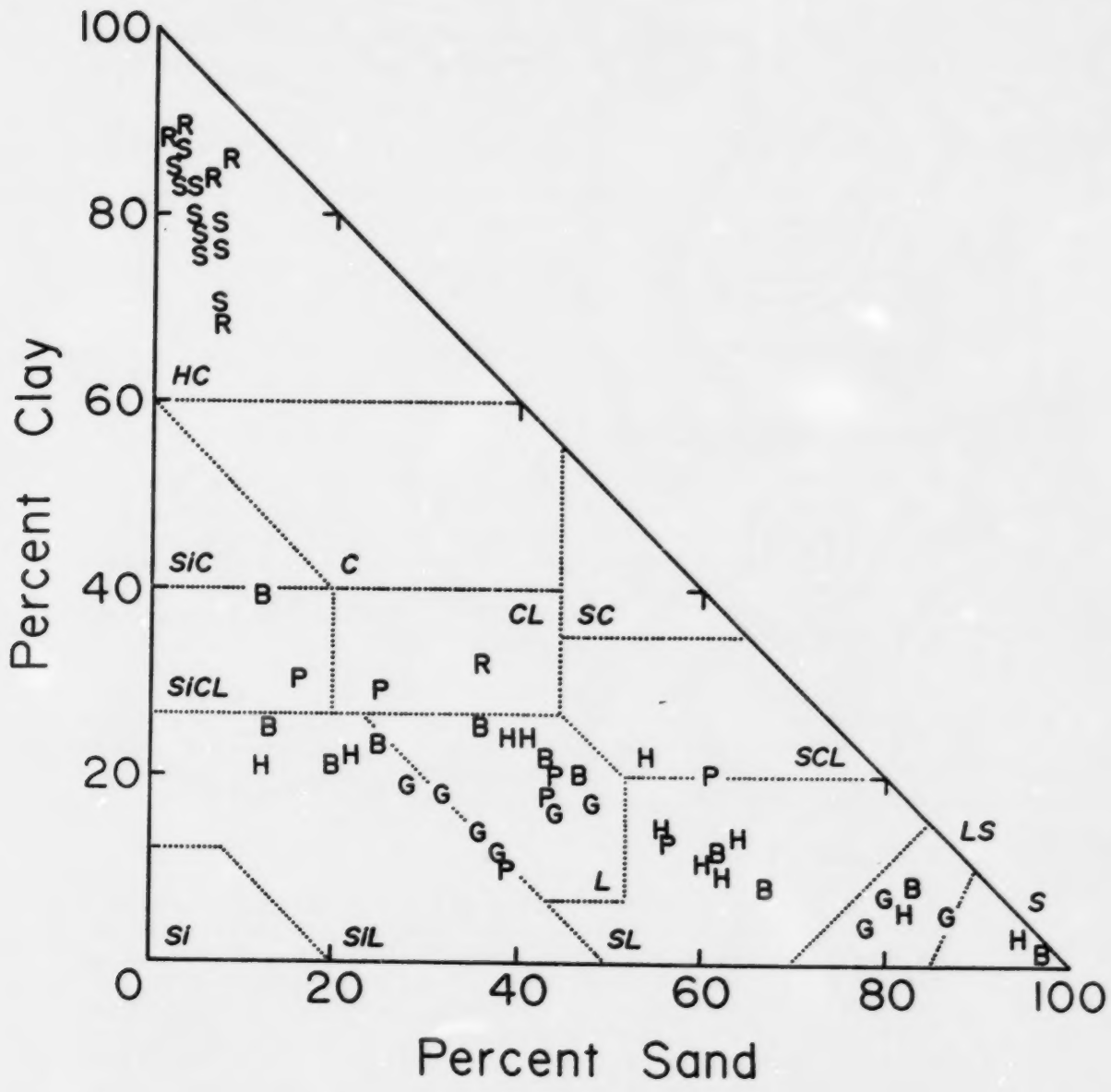

Figure 24: Sediment texture of samples collected from six study ponds (S,R,P,G,H,B) superimposed on soil texture classes given in C.S.S.C. (1977). HC=high clay, SiC=silty clay, C=clay, SC=sandy clay, SiCL=silty clay loam, CL=clay loam, SCL=sandy clay loam, SiL=silty loam, Si=silt, L=loam, SL=sandy loam, LS=loamy sand, S=sand. Overlapping points are not shown.

laboratory analytical procedures were not capable of greater accuracy. Such calculated statistics should be interpreted accordingly.

Further qualifications on these calculations are as follows:

1. statistical calculations were not performed when the number of data points (n) was less than 4.

2. mean pH was calculated as the log of the mean of the original concentrations of hydrogen ions.

3. the standard deviation ((n-1) degrees of freedom) was computed only for parameters that had an arithmetic mean.

Specific Conductivity & pH

Specific conductivity of all pondwaters was less than or equal to 500 uS/cm (Table 9). Although the range of conductivity over time observed in any one pond were generally <10% of the mean from 13 May to 12 December, the conductivity of Spruce Pond water (mean 474 uS/cm) was consistently higher than all other ponds (Table 9). The waters of Pine and Birch were the most dilute (89 uS/cm and 66 uS/cm respectively).

The pH of Spruce Pond water (7.80-8.65) was >0.5 units higher than all other ponds while Hike, Golden and Birch ponds were circumneutral (Table 10). Raspberry and Pine Pond waters were weakly acidic (6.40-7.15). Seasonal fluctuations showed no consistent trend and weekly variation was usually <0.3 unit.

Major Ions

The results of chemical analyses of pond water are tabulated sequentially in the following pages according to their valence. As a means of evaluating the relative contributions of some major cations and anions to total ionic concentrations (Tables 18,26), ion polygons were constructed after the method of Broch & Yake (1969) using the mean relative proportions (% total meq/L) of potassium, sodium, calcium, magnesium, sulphate, chloride, bicarbonate and carbonate (Figure 25). Other minor ions (eg. iron, manganese) do not contribute significantly to the total ion balance in these ponds and are therefore excluded.

The concentrations of positively charged ions in pond waters are given in Tables 11-17 and the sums of the major constituents (in meq/L) are compiled in Table 18. Total hardness (Table 15) was calculated from the concentrations of calcium and magnesium (mg/L) using the formula of Traversy (1971):

$$\text{Hardness (mg/L)} = ([Ca^{2+}] \times 2.497) + ([Mg^{2+}] \times 4.116)$$

Calcium and magnesium were the prevailing cations (cumulatively 71-94% of total cationic milliequivalents) in all experimental pond waters (Figure 25). As indicated by conductivity mea-

Table 9: Specific conductivity (uS/cm @ 25°C) of water collected from study ponds (1985). (. no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	438.0	81.9	39.9	98.8	122.0	46.5
	01	438.0	.	.	.	.	.
23 May	02	464.0	.	41.8	98.3	124.0	46.6
11 June	03	482.0	132.0	.	.	122.0	.
18 June	04	495.0	137.0	42.8	97.2	121.0	46.4
24 June	05	488.0	152.0	43.8	94.4	122.0	46.4
02 July	06	483.0	153.0	43.5	90.6	120.0	46.1
10 July	07	487.0	166.0	41.8	86.1	114.0	42.9
16 July	08	500.0	167.0	41.4	83.6	116.0	46.3
23 July	09	503.0	.	41.0	82.5	115.0	47.3
29 July	10	499.0	185.0	41.9	79.7	113.0	46.8
05 August	11	491.0	188.0	41.1	79.6	111.0	49.3
12 August	12	489.0	203.0	42.1	76.3	107.0	46.7
19 August	13	460.0	104.0	44.5	79.9	108.0	47.5
26 August	14	445.0	85.3	44.5	78.8	106.0	46.9
02 Sept.	16	462.0	95.2	47.3	81.3	108.0	47.3
09 Sept.	17	467.0	105.0	50.0	83.0	108.0	48.7
16 Sept.	18	464.0	112.0	50.8	85.3	109.0	48.8
24 Sept.	19	467.0	125.0	54.0	87.7	109.0	50.1
30 Sept.	20	471.0	134.0	55.9	89.9	111.0	50.5
08 Oct.	21	463.0	140.0	57.2	90.3	112.0	50.6
15 Oct.	22	462.0	135.0	57.4	91.6	110.0	51.3
21 Oct.	23	468.0	122.0	57.2	92.8	111.0	51.1
28 Oct.	24	469.0	124.0	57.6	94.6	111.0	51.7
28 Oct.	25	461.0	123.0	57.6	94.2	111.0	51.7
12 Dec.	26	518.0	139.0	.	112.0	131.0	59.8
	26	467.0	.	.	.	.	.
Minimum		438.0	81.9	39.9	76.3	106.0	42.9
Maximum		518.0	203.0	57.6	112.0	131.0	59.8
Median		468.0	134.0	44.5	88.8	111.0	47.4
Mean		474.1	135.1	47.6	88.7	114.1	48.6
StdDev(n-1)		19.8	31.9	6.7	8.4	6.5	3.3

Table 10: pH of water collected from study ponds (1985) (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	7.80	6.80	6.50	7.45	7.60	6.95
	01	8.05	.	.	.	.	.
23 May	02	8.10	6.70	6.65	7.35	7.50	7.05
11 June	03	8.15	6.95	6.70	7.25	7.60	6.85
18 June	04	7.95	6.80	6.90	7.55	7.70	7.10
24 June	05	8.10	6.80	6.70	7.50	7.75	7.00
02 July	06	8.05	7.00	6.90	7.55	7.60	7.30
10 July	07	8.20	6.90	6.70	8.10	8.20	7.40
16 July	08	8.25	7.00	6.45	7.45	7.85	7.00
23 July	09	8.15	6.95	6.70	7.70	7.95	7.10
29 July	10	8.20	7.05	6.90	8.05	8.30	7.45
05 August	11	8.45	7.15	6.85	8.55	8.45	7.30
12 August	12	8.00	7.05	6.55	7.50	7.50	7.00
19 August	13	7.90	6.55	6.45	7.15	7.20	6.80
26 August	14	8.30	6.40	7.05	7.50	8.00	7.15
02 Sept.	16	8.10	6.65	6.70	7.30	7.75	7.20
09 Sept.	17	8.15	6.45	6.50	7.10	7.45	6.75
16 Sept.	18	8.40	6.65	6.55	6.95	7.50	7.15
24 Sept.	19	8.20	6.65	6.55	7.05	7.35	6.70
30 Sept.	20	8.15	6.85	6.35	7.30	7.25	6.85
08 Oct.	21	8.15	6.90	6.30	7.10	7.30	6.65
15 Oct.	22	8.65	6.70	6.60	7.10	7.55	6.75
21 Oct.	23	8.45	6.80	6.60	7.35	7.45	6.70
28 Oct.	24	8.30	6.90	6.60	7.30	7.35	6.75
28 Oct.	25	8.30	6.75	6.45	7.15	7.50	6.95
12 Dec.	26	7.90	6.50	6.45	6.90	7.20	6.80
	26	7.95	.	.	.	.	.
Minimum		7.80	6.40	6.30	6.90	7.20	6.65
Maximum		8.65	7.15	7.05	8.55	8.45	7.45
Median		8.15	6.80	6.60	7.35	7.55	7.00
Mean		8.20	6.84	6.67	7.64	7.78	7.05
StdDev(n-1)		-	-	-	-	-	-

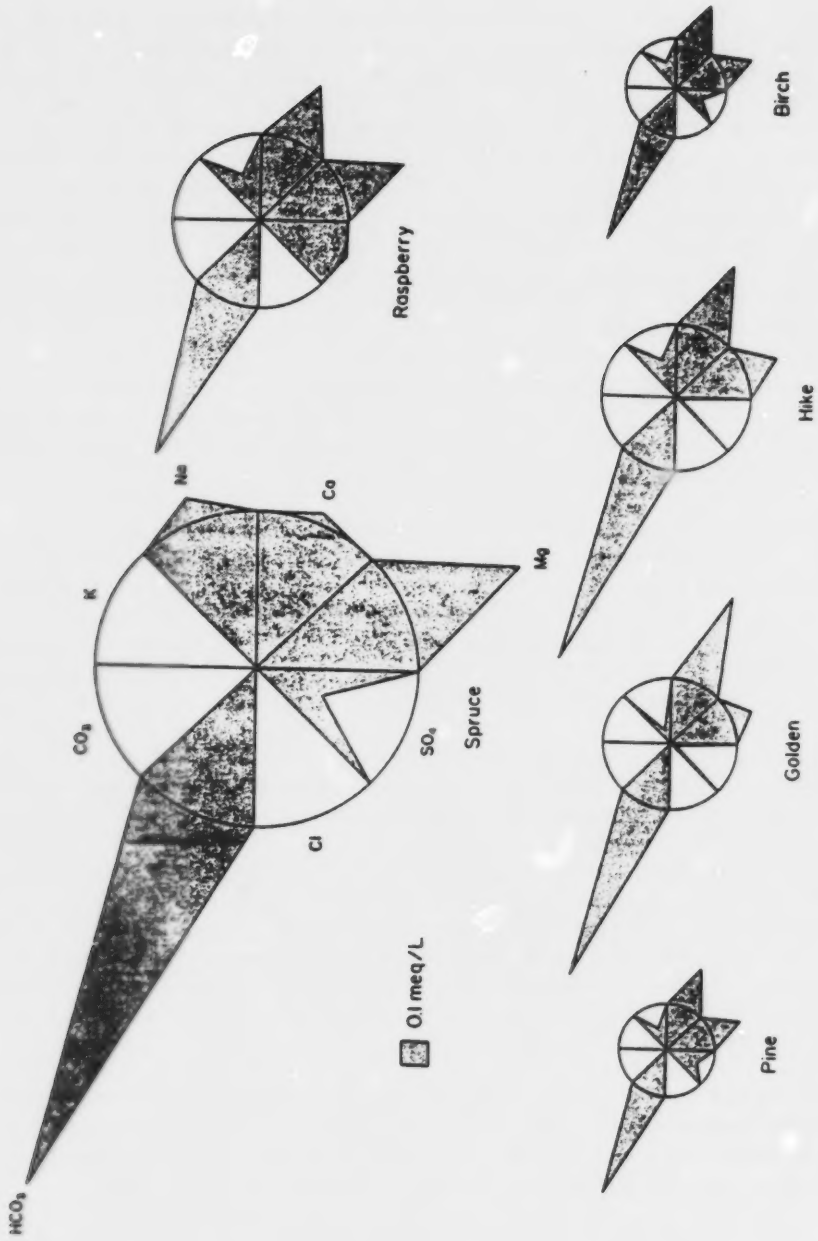

Figure 23: Ionic polygon diagrams representing the relative concentrations (% total meq) of major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (SO_4^{2-}, Cl^-, HCO_3^-, CO_3^{2-}) in water of the study ponds (1985). The absolute area of each segment of the diagram can be converted to the total milliequivalent concentration of each ion using the scale shown (Broch & Yake 1969).

surements (Table 9), the concentrations of sodium, calcium and magnesium (and consequently hardness) in Spruce Pond were 2-6 times higher than in all other ponds (Tables 11,13-15), while potassium levels (Table 12) were below the 5.0 mg/L limit of detection at all times in all ponds. Mean levels of these ions in Raspberry and Hike were greater than in Golden, Pine and Birch. Sodium levels in Golden (0.87-2.75 mg/L) were less than in Pine or Birch (means 1.38 mg/L and 1.72 mg/L respectively), but mean calcium and magnesium levels were higher than in the latter two ponds (Tables 13,14). Mean monovalent:divalent cationic ratios (meq/L) were 0.41 (Spruce), 0.16 (Raspberry, Hike, Birch), 0.14 (Pine) and 0.06 (Golden).

Total hardness (Table 15) was greatest in water from Spruce Pond (167-220 mg/L $CaCO_3$). Contributions of iron and manganese to hardness (Traversy 1971) were (2% of the total (data not shown) and were excluded from calculations.

The highest concentrations of extractable iron were found in Birch, Pine and Raspberry Ponds (means 2.57 mg/L, 1.39 mg/L and 0.99 mg/L respectively; Table 16). The levels in Spruce Pond were slightly above the 0.02 mg/L detection limit throughout the sampling period. Manganese was most abundant in water collected from Raspberry and Pine Ponds (Table 17), while corresponding levels in the remaining four ponds were usually < 0.5 mg/L.

Systematic changes in the concentrations of individual cations were detected over the period of sampling in some ponds. Sodium, calcium, magnesium, iron and manganese levels increased ca. 0.3 mg/L, 2.4 mg/L, 1.0 mg/L, 1.4 mg/L and 0.1 mg/L respectively in Pine Pond between 13 May and 12 December. Increases in calcium (ca. 0.6 mg/L) and iron (1.1 mg/L) in Birch Pond and iron (0.4 mg/L) in Raspberry Pond occurred over the same period. Between early July and late August, calcium levels in Golden Pond were lower than in samples collected at spring and fall (Table 13). Short-term fluctuations were observed between successive weeks in some ponds (Tables 11-17).

Estimates of total, bicarbonate, carbonate and hydroxide alkalinity were made from titration of water samples to pH 8.3 and 4.5 endpoints against a standard acid solution. Details of the calculation formulae are given in Sorba et al. (1980).

Except for Spruce Pond, all study ponds were weakly buffered (total alkalinity < 100 mg $CaCO_3$/L)(Table 19). In Spruce and Raspberry Pond, alkalinity increased ca. 20 mg/L from May to mid August, sharply decreased (19 August) and then increased 10-20 mg/L in the fall. In the most weakly buffered Pine and Birch Ponds (means 20.6 mg/L and 22.0 mg/L respectively), alkalinity increased ca. 6 and 4 mg/L respectively during the study period. Weekly and seasonal variations were not apparent in Golden and Hike Ponds (Table 19).

Table 11: Total extractable sodium concentration (mg/L) in water collected from study ponds (1985). (. = no data, < = below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	31.5	2.97	<1.0	.	3.24	.
	01	33.9	.	.	.	.	.
23 May	02	38.9	4.24	1.17	1.28	4.04	1.80
11 June	03	34.8	7.50	1.37	1.46	4.40	2.00
18 June	04	35.2	5.63	1.33	1.30	3.59	1.71
24 June	05	38.6	6.70	1.33	1.38	3.73	1.73
02 July	06	36.6	6.73	1.34	1.28	3.75	1.73
10 July	07	37.0	6.7	1.26	1.2	3.4	1.7
16 July	08	39.0	7.10	1.40	1.30	3.65	1.70
23 July	09	38.5	7.80	1.40	2.75	3.78	1.67
29 July	10	36.6	7.9	1.25	1.22	3.51	1.59
05 August	11	40.2	8.84	1.30	1.38	3.95	1.70
12 August	12	39.8	9.52	1.44	1.26	3.60	1.90
19 August	13	35.3	3.58	1.00	0.87	3.20	1.38
26 August	14	35.8	2.8	1.2	1.1	3.1	1.5
02 Sept.	16	33.1	3.11	1.16	1.10	3.18	1.47
09 Sept.	17	37.5	4.12	1.43	1.27	3.40	1.70
16 Sept.	18	37.1	4.5	1.5	1.3	3.7	1.8
24 Sept.	19	36.8	5.27	1.47	1.21	3.49	1.66
30 Sept.	20	38.4	6.02	1.53	1.30	3.61	1.71
08 Oct.	21	40.5	6.64	1.61	1.28	3.78	1.82
15 Oct.	22	38.7	6.33	1.58	1.31	3.70	1.77
21 Oct.	23	37.5	5.40	1.60	1.29	3.61	1.77
28 Oct.	24	40.9	6.15	1.65	1.33	3.75	1.74
28 Oct.	25	39.3	5.00	1.59	1.30	3.52	1.66
12 Dec.	26	36.3	5.48	1.69	1.47	3.95	2.00
	26	39.5	.	.	.	.	.
Minimum		31.5	2.80	<1.00	0.87	3.10	1.38
Maximum		40.9	9.52	1.69	2.75	4.40	2.00
Median		37.5	6.02	1.40	1.30	3.61	1.71
Mean		37.3	5.84	1.38*	1.33	3.63	1.72
StdDev(n-1)		2.3	1.79	0.19*	0.33	0.29	0.14

Table 12: Total extractable potassium concentration (mg/L) in water collected from study ponds (1985). (. = no data, < = below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	<5.00	<5.00	<5.00	.	<5.00	.
	01	<5.00	.	.	.	.	.
23 May	02	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
11 June	03	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
18 June	04	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
24 June	05	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
02 July	06	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
10 July	07	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
16 July	08	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
23 July	09	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
29 July	10	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
05 August	11	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
12 August	12	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
19 August	13	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
26 August	14	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
02 Sept.	16	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
09 Sept.	17	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
16 Sept.	18	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
24 Sept.	19	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
30 Sept.	20	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
08 Oct.	21	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
15 Oct.	22	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
21 Oct.	23	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
28 Oct.	24	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
28 Oct.	25	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
12 Dec.	26	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
	26	<5.00	.	.	.	.	.
Minimum		<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Maximum		<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Median		<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Mean		5.00*	5.00*	5.00*	5.00*	5.00*	5.00*
StdDev(n-1)		0*	0*	0*	0*	0*	0*

Table 13: Total extractable calcium concentration (mg/L) in water collected from study ponds (1985). (. = no data).

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	30.6	9.00	5.56	.	13.8	.
	01	29.2	.	.	.	.	.
23 May	02	35.3	11.1	4.23	13.6	15.5	5.18
11 June	03	31.3	14.2	4.45	12.9	14.0	4.67
18 June	04	30.6	14.3	4.16	13.0	14.0	4.47
24 June	05	32.1	16.1	4.30	12.5	14.0	4.50
02 July	06	29.8	15.6	3.94	11.4	12.5	4.33
10 July	07	30.2	16.8	4.0	10.6	12.1	4.5
16 July	08	27.7	15.8	3.87	9.50	11.9	4.46
23 July	09	30.2	18.2	4.25	9.89	11.4	4.42
29 July	10	28.8	17.8	3.94	8.9	10.7	2.48
05 August	11	29.6	19.1	4.40	9.65	11.2	4.50
12 August	12	29.8	19.8	4.32	9.15	10.5	4.51
19 August	13	28.0	12.0	4.91	10.0	10.9	4.73
26 August	14	24.6	9.1	4.0	8.2	8.9	4.0
02 Sept.	16	26.0	11.0	4.68	9.25	10.0	4.40
09 Sept.	17	27.3	12.9	5.32	10.2	10.9	5.00
16 Sept.	18	29.3	14.1	5.9	11.1	11.8	5.4
24 Sept.	19	27.7	14.4	6.04	10.7	11.3	5.23
30 Sept.	20	30.3	15.6	6.48	11.7	11.7	5.34
08 Oct.	21	33.0	17.4	6.86	12.5	12.7	5.83
15 Oct.	22	33.0	17.2	7.08	13.4	13.0	5.99
21 Oct.	23	33.0	15.8	7.06	13.2	13.0	6.09
28 Oct.	24	31.7	15.0	6.69	12.5	12.4	5.37
28 Oct.	25	30.7	14.9	6.60	12.7	11.7	5.24
12 Dec.	26	35.2	17.0	7.49	14.6	14.3	6.60
	26	35.0	.	.	.	.	.
Minimum		24.6	9.0	3.87	8.2	8.9	2.48
Maximum		35.3	19.8	7.49	14.6	15.5	6.60
Median		30.2	15.6	4.68	11.3	11.9	4.70
Mean		30.4	15.0	5.22	11.3	12.2	4.89
StdDev (n-1)		2.7	2.9	1.23	1.8	1.5	0.83

Table 14: Total extractable magnesium concentration (mg/L) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	25.3	5.59	1.93	.	4.66	.
	01	24.2	.	.	.	.	.
23 May	02	30.3	7.26	2.12	3.79	5.45	2.63
11 June	03	29.2	9.83	2.30	3.80	5.40	2.60
18 June	04	28.7	9.20	2.30	3.74	5.30	2.55
24 June	05	31.1	10.4	2.41	3.86	5.40	2.60
02 July	06	29.1	10.0	2.34	3.59	5.08	2.53
10 July	07	30.9	10.6	2.4	3.6	5.2	2.8
16 July	08	29.3	10.2	2.30	3.30	5.20	2.60
23 July	09	30.5	11.3	2.40	3.67	5.27	2.56
29 July	10	29.7	11.3	2.25	3.31	5.0	2.48
05 August	11	33.0	12.5	2.60	3.70	5.53	2.20
12 August	12	32.1	12.5	2.33	3.48	5.00	2.60
19 August	13	28.0	7.90	2.33	3.16	4.79	2.53
26 August	14	25.7	5.9	2.0	2.7	4.0	2.1
02 Sept.	16	26.9	6.95	2.32	3.13	4.50	2.31
09 Sept.	17	28.7	7.99	2.61	3.41	4.87	2.58
16 Sept.	18	30.1	8.6	2.8	3.6	5.1	2.7
24 Sept.	19	28.7	9.20	2.93	3.54	5.02	2.68
30 Sept.	20	31.2	9.93	3.12	3.83	5.11	2.71
08 Oct.	21	33.5	10.6	3.28	3.97	5.38	2.92
15 Oct.	22	33.1	10.6	3.35	4.19	5.45	2.92
21 Oct.	23	33.5	9.78	3.34	4.12	5.47	2.94
28 Oct.	24	32.6	9.61	3.28	3.98	5.26	2.65
28 Oct.	25	31.5	9.48	3.20	4.00	4.97	2.59
12 Dec.	26	32.1	10.2	3.38	4.34	5.60	3.04
	26	32.4	.	.	.	.	.
Minimum		24.2	5.59	1.93	2.70	4.00	2.10
Maximum		33.5	12.50	3.38	4.34	5.60	3.04
Median		30.3	9.83	2.40	3.69	5.20	2.60
Mean		30.1	9.50	2.62	3.66	5.12	2.62
StdDev(n-1)		2.5	1.78	0.47	0.37	0.36	0.22

Table 15: Total calculated (calcium + magnesium) hardness (mg/L) of water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	180.0	45.4	21.8	.	53.6	.
	01	172.0	.	.	.	.	.
23 May	02	212.0	57.5	19.2	49.5	61.1	27.8
11 June	03	198.0	75.9	20.5	47.8	57.1	22.3
18 June	04	194.0	73.5	19.8	47.8	56.7	21.6
24 June	05	208.0	83.0	20.6	47.1	57.1	21.9
02 July	06	194.0	80.1	19.4	43.2	52.1	21.2
10 July	07	202.0	85.5	19.8	41.2	51.6	22.7
16 July	08	189.0	81.4	19.1	37.3	51.1	21.8
23 July	09	200.0	91.9	20.4	39.8	50.1	21.5
29 July	10	194.0	90.9	19.1	35.8	47.3	16.4
05 August	11	209.0	99.1	21.6	39.3	50.7	20.2
12 August	12	206.0	100.8	20.6	37.1	46.7	21.9
19 August	13	185.0	62.4	21.8	37.9	46.9	22.2
26 August	14	167.0	47.0	18.2	32.0	38.6	18.6
02 Sept.	16	175.0	56.0	21.2	35.9	43.4	20.4
09 Sept.	17	186.0	65.0	24.0	39.5	47.2	23.1
16 Sept.	18	197.0	71.0	26.2	43.0	50.4	24.5
24 Sept.	19	187.0	73.8	27.1	41.6	48.8	24.0
30 Sept.	20	204.0	79.8	29.0	44.9	50.2	24.4
08 Oct.	21	220.0	87.6	30.6	47.5	53.8	26.5
15 Oct.	22	218.0	86.5	31.4	50.7	54.8	26.9
21 Oct.	23	220.0	79.7	31.7	49.9	54.9	27.3
28 Oct.	24	213.0	77.6	30.2	47.5	52.6	24.3
28 Oct.	25	206.0	76.2	29.6	48.5	49.6	23.7
12 Dec.	26	220.0	84.4	32.6	54.3	58.7	28.9
	26	220.0	.	.	.	.	.
Minimum		167.0	45.4	18.2	32.0	38.6	16.4
Maximum		220.0	100.8	32.6	54.3	61.1	28.9
Median		200.0	79.7	21.6	43.1	51.1	22.5
Mean		199.1	76.5	23.8	43.3	51.4	23.1
StdDev(n-1)		15.4	14.4	4.9	5.8	5.0	3.0

Table 16: Total extractable iron concentration in water collected from study ponds (1985). (. = no data, < = below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.03	0.68	0.92	.	0.16	.
	01	<0.02	.	.	.	.	.
23 May	02	0.04	0.60	0.74	0.16	0.12	2.44
11 June	03	0.03	0.70	0.96	0.18	0.17	2.17
18 June	04	0.04	0.74	0.69	0.19	0.12	1.86
24 June	05	0.05	0.86	0.83	0.16	0.19	2.01
02 July	06	0.04	0.83	0.76	0.11	0.10	1.94
10 July	07	0.04	1.48	0.87	0.14	0.17	1.92
16 July	08	.	1.20	0.79	0.18	0.14	2.00
23 July	09	0.03	0.97	0.68	0.15	0.17	2.02
29 July	10	0.03	0.72	0.69	0.12	0.14	1.87
05 August	11	0.03	0.60	0.67	0.09	0.10	1.74
12 August	12	0.04	0.73	0.95	0.15	0.22	2.13
19 August	13	0.03	0.91	1.29	0.26	0.27	2.42
26 August	14	.	.	.	.	.	.
02 Sept.	16	0.02	1.09	1.00	0.10	0.14	1.39
09 Sept.	17	0.02	1.30	1.50	0.21	0.30	2.20
16 Sept.	18	0.03	1.34	1.81	0.13	0.21	2.3
24 Sept.	19	0.02	1.16	2.16	0.19	0.36	3.44
30 Sept.	20	0.02	1.10	2.35	0.17	0.42	3.83
08 Oct.	21	0.02	1.15	2.80	0.21	0.57	4.34
15 Oct.	22	0.02	1.08	2.41	0.21	0.31	3.89
21 Oct.	23	<0.02	1.07	2.26	0.24	0.23	3.59
28 Oct.	24	0.05	1.09	2.10	0.39	0.19	3.25
28 Oct.	25	0.03	1.10	2.10	0.38	0.17	3.31
12 Dec.	26	0.05	1.29	1.52	0.36	0.09	2.95
	26	0.06	.	.	.	.	.
Minimum		<0.02	0.60	0.67	0.09	0.09	1.39
Maximum		0.06	1.48	2.80	0.39	0.57	4.34
Median		0.03	1.08	1.00	0.18	0.17	2.20
Mean		0.03*	0.99	1.37	0.19	0.21	2.57
StdDev(n-1)		0.01*	0.25	0.69	0.08	0.11	0.82

Table 17: Total extractable manganese concentration (mg/L) in water collected from study ponds (1985). (. = no data, < = below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.04	0.11	0.11	.	0.07	.
	01	<0.02	.	.	.	.	.
23 May	02	0.02	0.04	0.03	0.02	0.05	<0.02
11 June	03	0.03	0.11	0.12	0.03	0.08	0.02
18 June	04	0.04	0.23	0.03	0.03	0.05	0.02
24 June	05	0.05	0.27	0.07	0.03	0.12	0.02
02 July	06	0.03	0.16	0.03	<0.02	0.06	<0.02
10 July	07	0.04	0.65	0.05	0.02	0.07	0.02
16 July	08	0.05	0.27	0.78	0.02	0.06	0.02
23 July	09	0.03	0.20	0.04	0.02	0.08	0.03
29 July	10	0.08	0.14	0.05	0.02	0.05	<0.02
05 August	11	<0.02	0.14	0.04	<0.02	0.04	0.02
12 August	12	0.07	0.21	0.14	0.05	0.14	0.04
19 August	13	0.03	0.07	0.15	0.04	0.23	0.11
26 August	14	<0.02	0.08	0.04	<0.02	0.04	<0.02
02 Sept.	16	0.02	0.13	0.07	<0.02	0.06	0.02
09 Sept.	17	0.03	0.28	0.17	0.03	0.15	0.10
16 Sept.	18	<0.02	0.09	0.05	<0.02	0.04	0.04
24 Sept.	19	0.02	0.13	0.18	0.02	0.07	0.06
30 Sept.	20	<0.02	0.07	0.15	0.02	0.06	0.04
08 Oct.	21	<0.02	0.10	0.22	0.04	0.06	0.04
15 Oct.	22	<0.02	0.08	0.16	0.04	0.05	0.03
21 Oct.	23	0.04	0.06	0.18	0.04	0.05	0.03
28 Oct.	24	<0.02	0.06	0.17	0.12	0.05	0.02
28 Oct.	25	<0.02	0.06	0.17	0.12	0.04	0.02
12 Dec.	26	0.03	0.40	0.28	0.17	0.03	<0.02
	26	0.02	.	.	.	.	.
Minimum		0.02	0.04	0.03	0.02	0.03	0.02
Maximum		0.08	0.65	0.78	0.17	0.23	0.11
Median		0.03	0.13	0.12	0.03	0.06	0.02
Mean		0.03*	0.17	0.14	0.04*	0.07	0.03*
StdDev(n-1)		0.02*	0.13	0.15	0.04*	0.04	0.02*

Table 18: Total extractable cation concentration (meq/L) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	5.11	1.19	0.64	.	1.35	.
	01	5.05	.	.	.	.	.
23 May	02	6.07	1.49	0.59	1.18	1.53	0.77
11 June	03	5.61	2.00	0.63	1.15	1.47	0.74
18 June	04	5.48	1.80	0.54	1.08	1.36	0.64
24 June	05	5.90	2.04	0.56	1.07	1.38	0.65
02 July	06	5.60	2.05	0.60	1.05	1.34	0.69
10 July	07	5.72	2.12	0.55	0.95	1.25	0.66
16 July	08	5.56	2.04	0.54	0.87	1.25	0.65
23 July	09	5.75	2.28	0.56	0.98	1.24	0.64
29 July	10	5.54	2.25	0.52	0.83	1.16	0.53
05 August	11	6.00	2.45	0.58	0.91	1.25	0.61
12 August	12	5.92	2.52	0.57	0.87	1.16	0.66
19 August	13	5.30	1.50	0.59	0.87	1.15	0.66
26 August	14	4.96	1.12	0.48	0.74	0.97	0.50
02 Sept.	16	5.01	1.36	0.58	0.83	1.08	0.59
09 Sept.	17	5.48	1.65	0.72	0.98	1.23	0.74
16 Sept.	18	5.68	1.78	0.78	1.04	1.30	0.78
24 Sept.	19	5.47	1.87	0.82	1.01	1.27	0.80
30 Sept.	20	5.88	2.02	0.86	1.09	1.30	0.83
08 Oct.	21	6.23	2.13	0.85	1.08	1.32	0.83
15 Oct.	22	6.12	2.11	0.84	1.14	1.33	0.82
21 Oct.	23	6.10	1.93	0.84	1.13	1.33	0.82
28 Oct.	24	6.11	1.91	0.81	1.09	1.28	0.74
28 Oct.	25	5.90	1.84	0.80	1.09	1.22	0.73
12 Dec.	26	6.04	2.04	0.84	1.23	1.41	0.84
	26	6.19	.	.	.	.	.
Minimum		4.96	1.12	0.48	0.74	0.97	0.50
Maximum		6.23	2.52	0.86	1.23	1.53	0.84
Median		5.72	2.00	0.60	1.05	1.28	0.71
Mean		5.70	1.90	0.67	1.01	1.28	0.71
StdDev(n-1)		0.38	0.36	0.13	0.13	0.12	0.10

Table 19: Total alkalinity (mg/L $CaCO_3$) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	212.0	28.0	16.0	48.0	60.0	20.0
	01	210.0	.	.	.	.	.
23 May	02	226.0	40.0	22.0	50.0	64.0	22.0
11 June	03	230.0	48.0	22.0	48.0	58.0	20.0
18 June	04	232.0	50.0	18.0	48.0	60.0	20.0
24 June	05	236.0	60.0	18.0	46.0	58.0	20.0
02 July	06	234.0	58.0	16.0	44.0	56.0	18.0
10 July	07	236.0	68.0	18.0	42.0	58.0	20.0
16 July	08	236.0	70.0	16.0	40.0	56.0	18.0
23 July	09	242.0	76.0	18.0	38.0	56.0	20.0
29 July	10	242.0	82.0	16.0	38.0	54.0	20.0
05 August	11	232.0	76.0	16.0	36.0	52.0	20.0
12 August	12	242.0	92.0	20.0	38.0	56.0	28.0
19 August	13	222.0	36.0	18.0	38.0	50.0	22.0
26 August	14	228.0	26.0	20.0	40.0	52.0	22.0
02 Sept.	16	234.0	34.0	20.0	40.0	54.0	22.0
09 Sept.	17	232.0	38.0	20.0	42.0	54.0	22.0
16 Sept.	18	236.0	44.0	22.0	42.0	56.0	24.0
24 Sept.	19	230.0	50.0	24.0	42.0	54.0	22.0
30 Sept.	20	234.0	52.0	22.0	46.0	54.0	24.0
08 Oct.	21	232.0	58.0	24.0	44.0	54.0	24.0
15 Oct.	22	232.0	54.0	24.0	46.0	56.0	24.0
21 Oct.	23	232.0	48.0	26.0	46.0	58.0	22.0
28 Oct.	24	234.0	46.0	24.0	46.0	56.0	24.0
28 Oct.	25	234.0	46.0	24.0	46.0	54.0	24.0
12 Dec.	26	256.0	48.0	30.0	54.0	64.0	28.0
	26	256.0	.	.	.	.	.
Minimum		210.0	26.0	16.0	36.0	50.0	18.0
Maximum		256.0	92.0	30.0	54.0	64.0	28.0
Median		234.0	50.0	20.0	44.0	56.0	22.0
Mean		233.4	53.1	20.6	43.5	56.2	22.0
StdDev(n-1)		9.9	16.7	3.7	4.4	3.4	2.6

Fluctuation in the concentration of bicarbonate (determined by calculation from total alkalinity) were as described above (Table 20). Bicarbonate accounted for 74-98% of the mean total anionic milliequivalents (Table 26) in the study ponds (Figure 25). Hydroxide alkalinity and carbonate alkalinity in the ponds were usually negligible (Tables 21,22).

Chloride levels were below a 2.0 mg/L detection limit in all ponds throughout the sampling period (Table 23). Mean levels of fluoride and sulphate were ca. 2 times greater in Spruce Pond than in all others (Tables 24-25). There was no evidence of seasonal changes in fluoride levels although sulphate levels in all ponds but Spruce Pond decreased 0.5-10 mg/L during July and increased 0.8-8 mg/L in late August (Table 25). Sulphate accounted for significant portions of total anionic strength (Table 26) in Spruce (10.8%), Raspberry (25.9%), Pine (16.7%) and Birch (13.7%) Ponds.

Macronutrients

Levels of ammoniacal nitrogen (Table 27) and nitrate+nitrite nitrogen (Table 28) were generally < 0.02 mg/L and 0.01 mg/L respectively in all ponds during the study period. Ammonia concentrations increased irregularly to as high as 0.07 mg/L (Pine Pond - 12 August), although no temporal patterns were evident. Total Kjeldahl nitrogen (TKN) concentrations (Table 29) were highest in Raspberry (1.8 mg/L) and lowest in Golden, Hike and Birch Ponds (ca. 0.65 mg/L). Organic nitrogen, estimated as the difference between TKN and NH_3-N (APHA 1980), accounted for >95% of total nitrogen in all pondwater samples (data not shown).

Analyses of water samples for molybdate-reactive orthophosphorus and total molybdate-reactive phosphorus were performed on 16 July, 23 July, 29 July, 19 August, and 21 October. Whatman GF/C filtered (dissolved ortho-P) and unfiltered (total molybdate-reactive P) aliquots were analyzed within three hours of collection. Phosphorus was not detected in measurable quantities (<5 ug/L--Stainton et al. 1977) in either aliquot, in any pond.

Mean total phosphorus (TP) levels (Table 30) ranged from 0.023-0.025 (Hike, Birch and Spruce) to 0.055 (Pine). In Spruce Pond samples, TP concentration decreased over the study period from ca. 0.03 mg/L (early June) to 0.015 mg/L (October) while there was no significant change with time in Golden, Hike or Birch Ponds (Table 30). Levels in Raspberry and Pine Ponds increased gradually in early July, reached relative maxima of ca. 0.055 and 0.090 mg/L respectively in early September and decreased 0.025-0.035 mg/L into October.

Molybdate-reactive silica levels in Spruce Pond (Table 31) increased from ca. 1.4 mg/L in May and June to a maximum of 2.2 mg/L in late August and September, following by a decrease of ca. 0.5 mg/L in October. Levels in Raspberry and Pine Ponds increased from 1.6 and 1.7 mg/L respectively (13 May) to as high as 13.0 mg/L (Raspberry - 12 December) and 5.1 mg/L (Pine - 12 December).

Table 20: Bicarbonate alkalinity (mg/L HCO_3) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	259.0	34.2	19.5	58.6	73.2	24.4
	01	256.0	.	.	.	.	.
23 May	02	276.0	48.8	26.8	61.0	78.1	26.8
11 June	03	281.0	58.6	26.8	58.6	70.8	24.4
18 June	04	283.0	61.0	22.0	58.6	73.2	24.4
24 June	05	288.0	73.2	22.0	56.1	70.8	24.4
02 July	06	285.0	70.8	19.5	53.7	68.3	22.0
10 July	07	288.0	83.0	22.0	51.2	70.8	24.4
16 July	08	288.0	85.4	19.5	48.8	68.3	22.0
23 July	09	295.0	92.7	22.0	46.4	68.3	24.4
29 July	10	295.0	100.0	19.5	46.4	65.9	24.4
05 August	11	278.0	92.7	19.5	39.0	58.6	24.4
12 August	12	295.0	112.0	24.4	46.4	68.3	34.2
19 August	13	271.0	43.9	22.0	46.4	61.0	26.8
26 August	14	278.0	31.7	24.4	48.8	63.4	26.8
02 Sept.	16	285.0	41.5	24.4	48.8	65.9	26.8
09 Sept.	17	283.0	46.4	24.4	51.2	65.9	26.8
16 Sept.	18	283.0	53.7	26.8	51.2	68.3	29.3
24 Sept.	19	281.0	61.0	29.3	51.2	65.9	26.8
30 Sept.	20	285.0	63.4	26.8	56.1	65.9	29.3
08 Oct.	21	283.0	70.8	29.3	53.7	65.9	29.3
15 Oct.	22	268.0	65.9	29.3	56.1	68.3	29.3
21 Oct.	23	273.0	58.6	31.7	56.1	70.8	26.8
28 Oct.	24	285.0	56.1	29.3	56.1	68.3	29.3
28 Oct.	25	285.0	56.1	29.3	56.1	65.9	29.3
12 Dec.	26	312.0	58.6	36.6	65.9	78.1	34.2
	26	312.0	.	.	.	.	.
Minimum		256.0	31.7	19.5	39.0	58.6	22.0
Maximum		312.0	112.0	36.6	65.9	78.1	34.2
Median		283.0	61.0	24.4	53.7	68.3	26.8
Mean		283.4	64.8	25.1	52.9	68.3	26.8
StdDev(n-1)		12.5	20.4	4.5	5.8	4.5	3.2

Table 21: Carbonate alkalinity (mg/L CO_3) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.0	0.0	0.0	0.0	0.0	0.0
	01	0.0	.	.	.	.	.
23 May	02	0.0	0.0	0.0	0.0	0.0	0.0
11 June	03	0.0	0.0	0.0	0.0	0.0	0.0
18 June	04	0.0	0.0	0.0	0.0	0.0	0.0
24 June	05	0.0	0.0	0.0	0.0	0.0	0.0
02 July	06	0.0	0.0	0.0	0.0	0.0	0.0
10 July	07	0.0	0.0	0.0	0.0	0.0	0.0
16 July	08	0.0	0.0	0.0	0.0	0.0	0.0
23 July	09	0.0	0.0	0.0	0.0	0.0	0.0
29 July	10	0.0	0.0	0.0	0.0	0.0	0.0
05 August	11	2.4	0.0	0.0	2.4	2.4	0.0
12 August	12	0.0	0.0	0.0	0.0	0.0	0.0
19 August	13	0.0	0.0	0.0	0.0	0.0	0.0
26 August	14	0.0	0.0	0.0	0.0	0.0	0.0
02 Sept.	16	0.0	0.0	0.0	0.0	0.0	0.0
09 Sept.	17	0.0	0.0	0.0	0.0	0.0	0.0
16 Sept.	18	2.4	0.0	0.0	0.0	0.0	0.0
24 Sept.	19	0.0	0.0	0.0	0.0	0.0	0.0
30 Sept.	20	0.0	0.0	0.0	0.0	0.0	0.0
08 Oct.	21	0.0	0.0	0.0	0.0	0.0	0.0
15 Oct.	22	7.2	0.0	0.0	0.0	0.0	0.0
21 Oct.	23	4.8	0.0	0.0	0.0	0.0	0.0
28 Oct.	24	0.0	0.0	0.0	0.0	0.0	0.0
28 Oct.	25	0.0	0.0	0.0	0.0	0.0	0.0
12 Dec.	26	0.0	0.0	0.0	0.0	0.0	0.0
	26	0.0	.	.	.	.	.
Minimum		0.0	0.0	0.0	0.0	0.0	0.0
Maximum		7.2	0.0	0.0	2.4	2.4	0.0
Median		0.0	0.0	0.0	0.0	0.0	0.0
Mean		0.6	0	0	0.1	0.1	0
StdDev(n-1)		1.7	0	0	0.5	0.5	0

Table 22: Hydroxide alkalinity (mg/L OH) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.0	0.0	0.0	0.0	0.0	0.0
	01	0.0	.	.	.	.	.
23 May	02	0.0	0.0	0.0	0.0	0.0	0.0
11 June	03	0.0	0.0	0.0	0.0	0.0	0.0
18 June	04	0.0	0.0	0.0	0.0	0.0	0.0
24 June	05	0.0	0.0	0.0	0.0	0.0	0.0
02 July	06	0.0	0.0	0.0	0.0	0.0	0.0
10 July	07	0.0	0.0	0.0	0.0	0.0	0.0
16 July	08	0.0	0.0	0.0	0.0	0.0	0.0
23 July	09	0.0	0.0	0.0	0.0	0.0	0.0
29 July	10	0.0	0.0	0.0	0.0	0.0	0.0
05 August	11	0.0	0.0	0.0	0.0	0.0	0.0
12 August	12	0.0	0.0	0.0	0.0	0.0	0.0
19 August	13	0.0	0.0	0.0	0.0	0.0	0.0
26 August	14	0.0	0.0	0.0	0.0	0.0	0.0
02 Sept.	16	0.0	0.0	0.0	0.0	0.0	0.0
09 Sept.	17	0.0	0.0	0.0	0.0	0.0	0.0
16 Sept.	18	0.0	0.0	0.0	0.0	0.0	0.0
24 Sept.	19	0.0	0.0	0.0	0.0	0.0	0.0
30 Sept.	20	0.0	0.0	0.0	0.0	0.0	0.0
08 Oct.	21	0.0	0.0	0.0	0.0	0.0	0.0
15 Oct.	22	0.0	0.0	0.0	0.0	0.0	0.0
21 Oct.	23	0.0	0.0	0.0	0.0	0.0	0.0
28 Oct.	24	0.0	0.0	0.0	0.0	0.0	0.0
28 Oct.	25	0.0	0.0	0.0	0.0	0.0	0.0
12 Dec.	26	0.0	0.0	0.0	0.0	0.0	0.0
	26	0.0	.	.	.	.	.
Minimum		0.0	0.0	0.0	0.0	0.0	0.0
Maximum		0.0	0.0	0.0	0.0	0.0	0.0
Median		0.0	0.0	0.0	0.0	0.0	0.0
Mean		0	0	0	0	0	0
StdDev(n-1)		0	0	0	0	0	0

Table 23: Soluble chloride concentration (mg/L) in water collected from study ponds (1985). (. = no data, (= below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	2.0	3.0	<2.0	<2.0	<2.0	<2.0
	01	2.0	.	.	.	.	.
23 May	02	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
11 June	03	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
18 June	04	2.0	2.0	<2.0	<2.0	<2.0	<2.0
24 June	05	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
02 July	06	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
10 July	07	<2.0	2.0	1.0	<2.0	<1.0	<1.0
16 July	08	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
23 July	09	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
29 July	10	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
05 August	11	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
12 August	12	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
19 August	13	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
26 August	14	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
02 Sept.	16	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
09 Sept.	17	<2.0	3.0	<2.0	<2.0	<2.0	<2.0
16 Sept.	18	2.0	2.0	<2.0	<2.0	<2.0	<2.0
24 Sept.	19	2.0	2.0	<2.0	<2.0	<2.0	<2.0
30 Sept.	20	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
08 Oct.	21	<2.0	3.0	<2.0	<2.0	<2.0	<2.0
15 Oct.	22	<2.0	3.0	<2.0	<2.0	<2.0	<2.0
21 Oct.	23	<2.0	3.0	2.0	<2.0	<2.0	<2.0
28 Oct.	24	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
28 Oct.	25	<2.0	2.0	<2.0	<2.0	<2.0	<2.0
12 Dec.	26	<2.0	3.0	<2.0	<2.0	<2.0	<2.0
	26	<2.0	.	.	.	.	.
Minimum		<2.0	<2.0	<2.0	<2.0	<1.0	<1.0
Maximum		2.0	3.0	2.0	<2.0	<2.0	<2.0
Median		<2.0	2.0	<2.0	<2.0	<2.0	<2.0
Mean		2.0*	2.2*	2.0*	2.0*	2.0*	2.0*
StdDev(n-1)		0*	0.4*	0.2*	0*	0.2*	0.2*

Table 24: Fluoride concentration (mg/L) in water collected from study ponds (1985). (. = no data, < = below detection limit)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.25	0.11	<0.1	0.12	0.14	0.10
	01	0.25	.	.	.	.	.
23 May	02	0.27	<0.1	<0.1	<0.1	<0.1	0.12
11 June	03	0.26	0.10	<0.1	<0.1	0.12	0.10
18 June	04	0.26	0.11	<0.1	<0.1	0.11	<0.1
24 June	05	0.26	0.10	<0.1	<0.1	0.10	<0.1
02 July	06	0.28	0.11	<0.1	<0.1	0.14	0.10
10 July	07	0.31	0.13	<0.1	<0.1	0.12	<0.1
16 July	08	0.22	0.13	<0.1	<0.1	0.10	<0.1
23 July	09	0.26	0.14	<0.1	<0.1	0.15	0.12
29 July	10	0.26	0.13	<0.1	<0.1	0.12	<0.1
05 August	11	0.29	0.13	0.10	<0.1	0.14	<0.1
12 August	12	0.24	0.14	<0.1	<0.1	0.13	0.10
19 August	13	0.23	<0.1	<0.1	<0.1	0.10	<0.1
26 August	14	0.24	<0.1	<0.1	<0.1	0.12	<0.1
02 Sept.	16	0.26	<0.1	<0.1	<0.1	0.12	<0.1
09 Sept.	17	0.24	0.10	0.10	<0.1	0.12	0.10
16 Sept.	18	0.27	0.12	<0.1	<0.1	0.13	0.12
24 Sept.	19	0.26	0.10	0.12	<0.1	0.11	<0.1
30 Sept.	20	0.27	0.10	<0.1	<0.1	0.11	<0.1
08 Oct.	21	0.26	0.15	<0.1	0.10	0.10	<0.1
15 Oct.	22	0.27	0.10	<0.1	<0.1	0.11	<0.1
21 Oct.	23	0.27	0.10	<0.1	<0.1	0.12	0.10
28 Oct.	24	0.27	<0.1	<0.1	<0.1	0.10	<0.1
28 Oct.	25	0.27	<0.1	<0.1	<0.1	0.11	0.11
12 Dec.	26	0.30	0.10	<0.1	0.10	0.13	0.11
	26	0.29	.	.	.	.	.
Minimum		0.22	0.10	0.10	0.10	0.10	0.10
Maximum		0.31	0.15	0.12	0.12	0.15	0.12
Median		0.26	0.10	0.10	0.10	0.12	0.10
Mean		0.26	0.11*	0.10*	0.10*	0.12*	0.10*
StdDev(n-1)		0.02	0.02*	0.00*	0.00*	0.01*	0.01*

Table 25: Soluble sulphate concentration (mg/L) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	26.5	20.8	3.05	1.30	1.45	5.25
	01	26.0	.	.	.	.	.
23 May	02	25.0	16.0	3.40	1.60	2.00	3.90
11 June	03	25.3	28.0	3.0	0.80	7.5	2.80
18 June	04	31.0	29.0	3.40	0.80	0.80	2.70
24 June	05	38.0	28.0	3.20	1.15	1.25	2.60
02 July	06	27.0	23.0	3.40	0.60	1.20	2.60
10 July	07	33.0	23.0	4.60	2.20	1.80	3.80
16 July	08	10.8	10.6	4.0	1.3	1.4	3.2
23 July	09	33.0	26.0	3.2	0.5	0.5	2.1
29 July	10	26.5	8.5	3.0	0.70	0.60	2.30
05 August	11	38.0	28.0	2.5	0.6	0.90	2.3
12 August	12	25.0	10.6	2.6	1.0	1.1	2.6
19 August	13	28.0	12.2	2.8	0.8	1.0	2.2
26 August	14	33.0	7.0	3.8	0.8	0.8	2.6
02 Sept.	16	25.0	17.0	4.1	0.8	0.9	2.6
09 Sept.	17	30.0	18.5	4.6	0.8	0.7	3.2
16 Sept.	18	25.0	18.5	4.8	0.8	0.8	3.4
24 Sept.	19	25.0	15.5	5.2	0.8	1.6	4.4
30 Sept.	20	28.0	17.0	6.0	0.9	1.2	4.8
08 Oct.	21	30.0	14.0	5.25	1.0	1.1	5.4
15 Oct.	22	25.0	14.2	4.5	1.2	1.2	4.0
21 Oct.	23	28.0	17.0	4.8	1.5	1.1	3.7
28 Oct.	24	25.0	14.2	4.8	1.4	1.7	3.8
28 Oct.	25	33.0	13.8	4.8	1.7	1.4	3.8
12 Dec.	26	25.0	15.0	5.0	1.5	1.3	3.6
	26	29.0	.	.	.	.	.
Minimum		10.8	7.0	2.5	0.5	0.5	2.1
Maximum		38.0	29.0	6.0	2.2	7.5	5.4
Median		27.0	17.0	4.0	0.9	1.2	3.2
Mean		27.9	17.8	4.0	1.1	1.4	3.3
StdDev(n-1)		5.2	6.4	1.0	0.4	1.3	0.9

Table 26: Total extractable anion concentration (meq/L) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	4.85	1.08	0.44	.	1.29	.
	01	4.79	.	.	.	.	.
23 May	02	5.10	1.19	0.57	1.09	1.38	0.58
11 June	03	5.19	1.60	0.56	1.03	1.37	0.51
18 June	04	5.34	1.66	0.46	1.00	1.24	0.48
24 June	05	5.57	1.84	0.46	0.97	1.21	0.49
02 July	06	5.29	1.70	0.45	0.95	1.20	0.47
10 July	07	5.44	1.90	0.49	0.87	1.21	0.49
16 July	08	4.97	1.68	0.43	0.86	1.18	0.46
23 July	09	5.55	2.12	0.46	0.80	1.16	0.47
29 July	10	5.41	1.84	0.41	0.80	1.12	0.48
05 August	11	5.46	2.13	0.40	0.76	1.09	0.48
12 August	12	5.38	2.11	0.48	0.81	1.17	0.64
19 August	13	5.05	1.03	0.45	0.81	1.05	0.51
26 August	14	5.27	0.72	0.51	0.85	1.08	0.52
02 Sept.	16	5.22	1.09	0.51	0.85	1.13	0.52
09 Sept.	17	5.32	1.23	0.55	0.91	1.15	0.56
16 Sept.	18	5.37	1.32	0.59	0.91	1.19	0.61
24 Sept.	19	5.18	1.38	0.65	0.91	1.17	0.59
30 Sept.	20	5.31	1.45	0.62	0.99	1.16	0.64
08 Oct.	21	5.29	1.54	0.56	0.93	1.13	0.62
15 Oct.	22	5.18	1.46	0.60	0.97	1.17	0.59
21 Oct.	23	5.24	1.40	0.68	0.98	1.21	0.54
28 Oct.	24	5.22	1.27	0.61	0.98	1.18	0.59
28 Oct.	25	5.39	1.26	0.61	0.98	1.14	0.59
12 Dec.	26	5.66	1.36	0.73	1.14	1.34	0.66
	26	5.14	.	.	.	.	.
Minimum		4.79	0.72	0.40	0.76	1.05	0.46
Maximum		5.66	2.13	0.73	1.14	1.38	0.66
Median		5.29	1.45	0.51	0.92	1.17	0.53
Mean		5.27	1.49	0.53	0.92	1.19	0.55
StdDev(n-1)		0.20	0.36	0.09	0.10	0.08	0.06

Table 27: Dissolved ammonia-nitrogen concentration (mg/L) in water collected from study ponds (1985). (. = no data, < = below detection limit). Multiply reported data by 1.216 to yield mg/L NH_3 (Sorba et al. 1980).

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	01	<0.02	.	.	.	.	.
23 May	02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
11 June	03	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
18 June	04	0.009	0.033	0.010	0.006	0.014	0.011
24 June	05	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
02 July	06	<0.02	0.03	0.02	<0.02	<0.02	<0.02
10 July	07	0.02	0.06	0.02	0.02	0.02	0.02
16 July	08	0.02	0.05	<0.02	0.03	0.03	0.02
23 July	09	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
29 July	10	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
05 August	11	0.039	0.050	0.048	0.039	0.029	0.019
12 August	12	<0.02	<0.02	0.07	<0.02	<0.02	<0.02
19 August	13	<0.02	0.02	0.02	0.02	<0.02	<0.02
26 August	14	0.012	0.024	0.024	0.009	0.006	0.010
02 Sept.	16	0.007	0.024	0.011	0.011	0.005	0.045
09 Sept.	17	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
16 Sept.	18	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
24 Sept.	19	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
30 Sept.	20	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
08 Oct.	21	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
15 Oct.	22	<0.02	0.02	<0.02	<0.02	<0.02	0.02
21 Oct.	23	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
28 Oct.	24	<0.02	0.03	0.02	<0.02	<0.02	0.03
28 Oct.	25	<0.02	0.03	0.02	<0.02	<0.02	0.03
12 Dec.	26	0.02	0.04	0.06	0.07	0.04	0.05
	26	0.02	.	.	.	.	.
Minimum		0.007	0.02	0.01	0.006	0.005	0.01
Maximum		0.039	0.06	0.07	0.07	0.04	0.05
Median		0.02	0.02	0.02	0.02	0.02	0.02
Mean		0.02*	0.03*	0.02*	0.02*	0.02*	0.02*
StdDev(n-1)		0.01*	0.01*	0.01*	0.01*	0.01*	0.01*

Table 28: Dissolved nitrate+nitrite-nitrogen concentration (mg/L) in water collected from study ponds (1985). (. = no data, (= below detection limit). Multiply reported values by ca. 4 to yield mg/L NO_3+NO_2 (Sorba et al. 1980).

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
	01	(0.01	.	.	.	.	.
23 May	02	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
11 June	03	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
18 June	04	(0.01	(0.01	(0.01	(0.001	(0.01	(0.01
24 June	05	(0.01	(0.01	(0.01	(0.01	(0.01	0.10
02 July	06	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
10 July	07	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
16 July	08	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
23 July	09	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
29 July	10	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
05 August	11	(0.01	(0.01	(0.01	(0.01	(0.01	0.01
12 August	12	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
19 August	13	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
26 August	14	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
02 Sept.	16	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
09 Sept.	17	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
16 Sept.	18	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
24 Sept.	19	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
30 Sept.	20	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
08 Oct.	21	0.04	0.01	(0.01	(0.01	0.01	0.01
15 Oct.	22	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
21 Oct.	23	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
28 Oct.	24	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
28 Oct.	25	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
12 Dec.	26	(0.01	(0.01	(0.01	(0.01	(0.01	(0.01
	26	(0.01	.	.	.	.	.
Minimum		(0.01	(0.01	(0.01	(0.001	(0.01	(0.01
Maximum		0.04	0.01	(0.01	(0.01	0.01	0.01
Median		0.01	0.01	(0.01	(0.01	(0.01	(0.01
Mean		0.01*	0.01*	0.01*	0.01*	0.01*	0.01*
StdDev(n-1)		0.01*	0*	0*	0*	0*	0*

Table 29: Total Kjeldahl nitrogen concentration (mg/L) in water collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.90	1.6	0.70	0.50	0.60	0.60
	01	0.90	.	.	.	.	.
23 May	02	0.90	1.6	0.60	0.55	0.55	0.60
11 June	03	1.1	1.7	0.85	0.70	0.70	0.60
18 June	04	1.1	1.8	1.1	0.70	0.70	0.70
24 June	05	1.2	1.7	1.0	0.70	0.70	0.70
02 July	06	1.1	1.6	1.0	0.70	0.60	0.70
10 July	07	1.2	1.9	1.0	0.80	0.70	0.70
16 July	08	1.1	1.8	1.4	0.70	0.60	0.60
23 July	09	1.1	1.7	1.1	0.70	0.70	0.70
29 July	10	1.0	1.6	1.3	0.70	0.70	0.70
05 August	11	1.0	1.7	0.80	0.70	0.50	0.65
12 August	12	1.1	1.6	1.1	0.70	0.55	0.70
19 August	13	0.95	1.9	0.85	0.75	0.65	0.70
26 August	14	1.0	2.2	0.90	0.65	0.55	0.65
02 Sept.	16	1.0	2.1	1.3	0.60	0.60	0.70
09 Sept.	17	1.0	2.0	1.2	0.70	0.50	0.70
16 Sept.	18	0.90	2.0	1.2	0.55	0.50	0.60
24 Sept.	19	1.0	1.9	1.1	0.70	0.55	0.70
30 Sept.	20	0.95	1.8	1.0	0.60	0.60	0.70
08 Oct.	21	1.0	1.9	1.1	0.60	0.60	0.70
15 Oct.	22	0.90	1.8	1.0	0.70	0.60	0.70
21 Oct.	23	1.0	1.8	1.1	0.65	0.60	0.60
28 Oct.	24	1.0	1.8	1.2	0.70	0.75	0.70
28 Oct.	25	1.0	1.9	1.2	0.70	0.65	0.70
12 Dec.	26	1.1	2.3	1.3	1.6	0.80	0.70
	26	1.1	.	.	.	.	.
Minimum		0.90	1.6	0.6	0.50	0.50	0.60
Maximum		1.2	2.3	1.4	1.60	0.80	0.70
Median		1.0	1.8	1.1	0.70	0.60	0.70
Mean		1.0	1.8	1.1	0.71	0.62	0.67
StdDev(n-1)		0.1	0.2	0.2	0.20	0.08	0.04

Table 30: Total phosphorus concentration (mg/L) in water collected from study ponds (1985) (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0.04	0.04	0.03	0.03	0.04	0.03
	01	0.03	.	.	.	.	.
23 May	02	0.035	0.030	0.030	0.020	0.035	0.025
11 June	03	0.03	0.04	0.03	0.02	0.03	0.02
18 June	04	0.035	0.055	0.055	0.025	0.020	0.020
24 June	05	0.025	0.040	0.045	0.025	0.025	0.025
02 July	06	0.04	0.04	0.05	0.03	0.03	0.04
10 July	07	0.020	0.025	0.040	0.020	0.015	0.02
16 July	08	0.025	0.045	0.10	0.025	0.02	0.02
23 July	09	0.025	0.04	0.06	0.02	0.02	0.02
29 July	10	0.025	0.04	0.08	0.02	0.02	0.02
05 August	11	0.025	0.065	0.045	0.025	0.025	0.020
12 August	12	0.025	0.035	0.055	0.015	0.025	0.030
19 August	13	0.030	0.050	0.050	0.025	0.035	0.030
26 August	14	0.020	0.055	0.035	0.025	0.020	0.025
02 Sept.	16	0.025	0.055	0.090	0.025	0.025	0.055
09 Sept.	17	0.025	0.050	0.050	0.025	0.020	0.025
16 Sept.	18	0.015	0.055	0.090	0.015	0.015	0.030
24 Sept.	19	0.030	0.035	0.060	0.020	0.020	0.030
30 Sept.	20	0.015	0.030	0.040	0.020	0.015	0.020
08 Oct.	21	0.015	0.035	0.050	0.025	0.020	0.015
15 Oct.	22	0.015	0.030	0.055	0.055	0.015	0.020
21 Oct.	23	0.015	0.030	0.060	0.030	0.015	0.020
28 Oct.	24	0.020	0.035	0.060	0.040	0.025	0.025
28 Oct.	25	0.015	0.040	0.055	0.035	0.020	0.020
12 Dec.	26	0.015	0.030	0.060	0.25	0.025	0.015
	26	0.015	.	.	.	.	.
Minimum		0.015	0.025	0.030	0.015	0.015	0.015
Maximum		0.040	0.065	0.100	0.250	0.040	0.055
Median		0.025	0.040	0.055	0.025	0.020	0.020
Mean		0.024	0.041	0.055	0.035	0.023	0.025
StdDev(n-1)		0.008	0.010	0.019	0.046	0.007	0.009

Table 31: Total molybdate-reactive silica concentration (mg/L) in water collected from study ponds (1985) (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	1.4	1.6	1.7	2.6	3.4	3.2
	01	1.3	.	.	.	.	.
23 May	02	1.4	1.4	1.8	2.2	3.1	3.3
11 June	03	1.4	2.6	1.7	1.7	2.3	2.6
18 June	04	1.2	3.0	1.6	1.5	1.8	2.6
24 June	05	1.6	3.4	1.8	1.5	1.8	2.5
02 July	06	1.5	4.0	1.6	1.2	1.8	2.2
10 July	07	1.2	4.1	1.2	0.4	1.8	2.0
16 July	08	1.3	3.8	1.1	1.0	1.6	1.6
23 July	09	1.5	4.2	1.4	1.0	1.9	1.6
29 July	10	1.6	3.9	1.3	0.7	1.4	1.4
05 August	11	0.8	3.2	1.0	0.6	1.4	1.0
12 August	12	1.7	3.6	1.2	0.6	1.5	1.0
19 August	13	2.2	8.4	2.4	1.5	2.3	2.0
26 August	14	2.2	9.3	3.5	1.2	2.0	1.8
02 Sept.	16	2.0	8.8	2.9	1.3	2.3	1.8
09 Sept.	17	2.2	8.8	3.6	1.3	2.2	2.2
16 Sept.	18	2.0	9.1	3.6	1.3	2.4	2.2
24 Sept.	19	2.4	9.4	4.3	1.2	2.4	2.5
30 Sept.	20	2.2	9.5	4.5	1.2	2.2	2.6
08 Oct.	21	2.0	9.4	4.8	1.2	2.1	2.8
15 Oct.	22	1.6	9.6	4.6	1.1	2.0	2.6
21 Oct.	23	1.6	10.0	5.0	1.2	2.0	2.8
28 Oct.	24	1.5	7.7	4.8	1.2	2.0	2.8
28 Oct.	25	1.5	7.8	4.8	1.2	2.0	2.8
12 Dec.	26	1.6	13.0	5.1	1.8	2.2	3.3
	26	1.6	.	.	.	.	.
Minimum		0.8	1.4	1.0	0.4	1.4	1.0
Maximum		2.4	13.0	5.1	2.6	3.4	3.3
Median		1.6	7.7	2.4	1.2	2.0	2.5
Mean		1.6	6.4	2.9	1.3	2.1	2.3
StdDev(n-1)		0.4	3.3	1.5	0.5	0.5	0.6

Initial SiO_2 levels in Golden, Hike and Birch Ponds were ca. twice as high as in the other three ponds during the same period, although they decreased to relative minima in late July and early August (Table 31) and increased 0.8-2.3 mg/L in the fall.

Other Compounds

Duplicate water samples from each pond were analyzed for dissolved total organic carbon (DOC) on three dates (Table 32). Although the data are insufficient to detect temporal trends, DOC was consistently highest in Raspberry Pond water samples (67.6 mg/L) and lowest in Golden and Hike Pond samples (ca. 10.4 mg/L). Levels in other ponds ranged from 15.6 mg/L (Birch) to 27.0 mg/L (Pine).

3.2.2 Sediment

Sediment samples were collected from eight to thirteen sites in each pond (Figures 18-23). Relative variation in specific parameters between sites in a given pond was represented by the coefficient of variation (CV, the ratio of the standard deviation to the mean multiplied by 100).

Salinity & pH

The salinity (specific conductivity x 10^3) of aqueous saturation pastes of Spruce Pond sediment samples (1.4-2.3 mS/cm; CV=16%) was similar to the range of samples from Raspberry (0.6-2.3 mS/cm; CV=38%) but were 5-20 times higher than values for all other pond samples. Salinities of samples from Pine, Golden, Hike and Birch Ponds were < 0.3 mS/cm (Table 33) except for the site 1 (0.6 mS/cm) and site 7 (5.6 mS/cm) samples from Hike Pond (Figure 28).

Sediment pH (aqueous saturation paste) was 0.1-0.2 units higher in Raspberry Pond samples than in Spruce Pond samples (means 7.8 and 7.7 respectively). Samples from all other ponds (Table 34) were moderately acidic (pH 5.1-5.9). Variation between sites in any given pond was < 1.5 units.

Major Ions

Levels of exchangeable (1N ammonium acetate) sodium in sediment samples from Spruce and Raspberry Ponds were similar (225 ppm and 201 ppm respectively). Maximum inter-site variation was < 95 ppm in Spruce Pond (CV=12%) but was 270 ppm (CV=49%) in Raspberry Pond (Table 35). Sodium concentrations were ca. 180 ppm lower in the remaining four ponds, particularly in Birch (mean 26 ppm; CV=31%) where levels were 10-20 ppm lower than in Pine (39 ppm; CV=36%), Golden (35 ppm; CV=11%) and Hike (46 ppm; CV=33%).

Exchangeable potassium levels were highest in all Spruce Pond samples (413-495 ppm; CV=5%), lower and more variable in Raspberry Pond (135-448 ppm; CV=28%) and lowest in the other four ponds (means 101-179 ppm)(Table 36). In the latter ponds, potas-

Table 32: Dissolved organic carbon concentration (mgC/L) in water collected from study ponds (1985) (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	.	.	.	.	.	.
23 May	02	.	.	.	.	.	.
11 June	03	.	.	.	.	.	.
18 June	04	.	.	.	.	.	.
24 June	05	.	.	.	.	.	.
02 July	06	.	.	.	.	.	.
10 July	07	.	.	.	.	.	.
16 July	08	.	.	.	.	.	.
23 July	09	.	.	.	.	.	.
29 July	10	.	.	.	.	.	.
05 August	11	.	.	.	.	.	.
12 August	12	.	.	.	.	.	.
19 August	13	.	.	.	.	.	.
26 August	14	.	.	.	.	.	.
02 Sept.	16	.	.	.	.	.	.
09 Sept.	17	.	.	.	.	.	.
16 Sept.	18	22.2	75.1	25.8	10.2	11.9	19.2
	18	21.6	75.1	25.8	11.7	11.9	18.6
24 Sept.	19	.	.	.	.	.	.
30 Sept.	20	.	.	.	.	.	.
08 Oct.	21	.	.	.	.	.	.
15 Oct.	22	21.6	66.1	27.0	10.1	9.6	19.2
	22	21.6	67.9	27.0	10.7	10.1	18.0
21 Oct.	23	19.8	59.5	22.8	9.4	10.0	16.8
	23	20.4	61.9	22.2	10.2	9.4	15.6
28 Oct.	24	.	.	.	.	.	.
28 Oct.	25	.	.	.	.	.	.
12 Dec.	26	.	.	.	.	.	.
Minimum		19.8	59.5	22.2	9.4	9.4	15.6
Maximum		22.2	75.1	27.0	11.7	11.9	19.2
Median		21.6	67.0	25.8	10.2	10.0	18.3
Mean		21.2	67.6	25.1	10.4	10.5	17.9
StdDev(n-1)		0.9	6.5	2.1	0.8	1.1	1.4

Table 33: Salinity (mS/cm) of surficial sediments from study ponds (25-26/09/85). See Fig.18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	1.9	2.3	0.3	0.1	0.6	0.2
2	1.9	1.3	0.3	0.2	0.3	0.2
3	2.3	1.2	0.1	0.2	0.1	0.2
4	1.9	1.4	0.1	0.2	0.2	0.2
5	1.6	0.6	0.1	0.1	0.2	0.2
6	1.9	0.8	0.2	0.1	0.3	0.2
7	1.9	1.5	0.2	0.1	5.6	0.1
8	2.2	1.6	0.1	0.2	0.1	0.1
9	1.5	0.7		0.2	0.2	0.1
10	2.1			0.2	0.2	0.1
11	1.4				0.1	0.1
12	1.9				0.2	0.2
13						0.2
Minimum	1.4	0.6	0.1	0.1	0.1	0.1
Maximum	2.3	2.3	0.3	0.2	5.6	0.2
Median	1.9	1.3	0.2	0.2	0.2	0.2
Mean	1.9	1.3	0.2	0.2	0.7	0.2
StdDev(n-1)	0.3	0.5	0.1	0.1	1.6	0.1

Table 34: pH of surficial sediments from study ponds (25-26/09/85). See Fig. 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	7.6	7.8	5.8	5.7	6.3	5.2
2	7.7	7.9	5.1	5.4	5.4	5.1
3	7.6	7.9	5.3	5.9	5.8	5.0
4	7.7	7.8	5.5	5.5	5.4	4.7
5	7.9	7.5	5.3	6.1	5.7	4.9
6	7.7	7.8	5.4	5.7	6.5	4.9
7	7.6	7.8	5.0	5.9	5.6	4.9
8	7.7	7.8	5.2	5.9	5.7	5.0
9	7.6	7.9		6.0	5.7	5.1
10	7.7			6.3	5.4	5.0
11	7.7				5.8	5.7
12	7.7				5.1	4.8
13						4.9
Minimum	7.6	7.5	5.0	5.4	5.1	4.7
Maximum	7.9	7.9	5.8	6.3	6.5	5.7
Median	7.7	7.8	5.3	5.9	5.7	5.0
Mean	7.7	7.8	5.4	5.9	5.9	5.1
StdDev(n-1)	-	-	-	-	-	-

Table 35: Exchangeable sodium (1N NH_4OAc) concentration (ppm) in sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	210	190	70	32	62	42
2	170	355	36	42	38	24
3	215	135	24	34	62	26
4	240	280	34	28	38	30
5	220	88	40	40	52	32
6	235	125	32	36	42	28
7	265	310	32	32	64	22
8	265	235	42	36	40	28
9	235	94		36	62	18
10	220			36	26	16
11	190				18	10
12	240				42	24
13						34
Minimum	170	88	24	28	18	10
Maximum	265	355	70	42	64	42
Median	228	190	35	36	42	26
Mean	225	201	39	35	46	26
StdDev(n-1)	28	98	14	4	15	8

Table 36: Exchangeable potassium (1N NH_4OAc) concentration (ppm) in sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	437	405	419	12	227	213
2	460	448	165	195	140	52
3	450	425	99	110	152	150
4	468	460	107	49	83	282
5	495	135	245	53	155	155
6	495	380	135	117	44	137
7	424	337	155	129	169	110
8	475	432	105	162	75	163
9	413	278		143	182	85
10	449			35	155	70
11	445				35	17
12	445				190	172
13						210
Minimum	413	135	99	12	35	17
Maximum	495	460	419	195	227	282
Median	450	405	145	114	154	150
Mean	455	367	179	101	134	140
StdDev(n-1)	25	104	108	60	61	73

sium concentrations varied by 46-60% of the mean between sites.

Calcium and magnesium were the dominant cations in the sediments from all ponds (cumulative 85-96% of total cationic strength--data not shown). The relative contribution of Mg^{2+} was higher in Spruce Pond (30%) and Raspberry Pond (29%) than in the remaining four ponds (14-20%), while that of Ca^{2+} was constant (66-72%). The absolute exchangeable calcium concentration was highest in Spruce Pond (mean 8299 ppm) and Raspberry Pond (7826 ppm) sediment samples and 3-10 times lower in all other ponds (range of means 737-117 ppm)(Table 37). Exchangeable magnesium levels in Spruce and Raspberry Pond samples (mean 2077 ppm and 2322 ppm respectively) were > 10 times higher than in the other four ponds (Table 38). Variation between sites, which was similar for the two cations, was low in Spruce (5%/6%), higher in Raspberry (30%/28%) and highest in Pine (59%/56%), Golden (47%/45%), Hike (51%/50%) and Birch (43%/43%) Ponds.

The monovalent:divalent ratio (meq/L) for the six ponds varied from 0.03 (Spruce, Raspberry) to 0.8 (Golden, Hike), 0.9 (Pine) and 1.0 (Birch). The sodium absorption ratio (SAR) of sediment samples was calculated as follows (Richards 1954):

$$SAR = [Na^{+}] / ([Ca^{2+}] + [Mg^{2+}])^{1/2}$$

with concentrations expressed in meq/L. Mean values for the six study ponds were 0.56 (Spruce), 0.52 (Raspberry), 0.29 (Pine), 0.31 (Golden), 0.34 (Hike) and 0.23 (Birch).

Extractable iron (0.005M DTPA) levels in surficial sediments ranged from 41 ppm (site 11--Birch) to 150 ppm (site 1--Pine). Within this range, there was overlap between samples from each pond (Table 39). The mean (and median) iron concentration of Spruce Pond (56 ppm; CV=7%) and Raspberry Pond (59 ppm; CV=37%) samples were, however, 7-27 ppm lower than in Pine Pond (83 ppm; CV=33%), Golden Pond (65 ppm; CV=12%), Hike Pond (69 ppm; CV=12%) and Birch Pond (76 ppm; CV=14%) samples.

Extractable manganese levels in sediments of Spruce Pond (25.0-32.0 ppm) were similar to those in all other ponds (Table 40). Spatial variability was greatest in Raspberry Pond (CV=35%), Golden Pond (28%) and Birch Pond (39%) and least in Pine Pond (13%), Spruce Pond (8%) and Hike Pond (2%).

Extractable sulphate levels were greater than the 20.0 ppm analytical limit in all samples from Spruce and Raspberry Ponds (Table 41). All samples but one collected at site 11 in Hike (Figure 22) were also reported as >20.0 ppm, while selected samples from Pine, Golden and Birch Ponds were also beyond this limit. Sulphate levels at sites 1-3,5-8 in Golden Pond (Figure 21) were from 0.4-8.0 ppm, although higher levels (>10 ppm) were found at sites 4,9-10. Samples 4,6-11 from the south-central basin of Birch Pond (Figure 17,23) contained 3.0 ppm (site 11) to 9.4 ppm (site 6) SO_4^{2-}. Levels at sites 3,4 and 8 in Pine Pond were 2.8-4.8 ppm (Table 41).

Table 37: Exchangeable calcium (1N NH_4OAc) concentration (ppm) in sediment samples collected from study ponds (25-26 September, 1985). See Figure 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	8030	9480	2520	180	2560	1380
2	8500	8200	780	820	840	400
3	7670	8880	640	1340	880	860
4	8940	8660	820	640	680	1040
5	8430	1620	1340	440	1180	820
6	8600	8260	880	960	740	800
7	8110	7960	800	940	1680	700
8	8550	8670	700	1160	680	900
9	7820	8700		1320	1380	540
10	8800			500	1040	420
11	7980				440	120
12	8160				1300	800
13						800
Minimum	7670	1620	640	180	440	120
Maximum	8940	9480	2520	1340	2560	1380
Median	8295	8660	810	880	960	800
Mean	8299	7826	1060	830	1117	737
StdDev(n-1)	396	2369	627	388	574	316

Table 38: Exchangeable magnesium (1N NH_4OAc) concentration (ppm) in sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	2470	2050	370	28	300	220
2	2420	2610	92	110	300	58
3	2100	2050	76	130	130	130
4	2380	2440	150	68	130	150
5	2330	640	260	54	86	130
6	2230	2180	180	120	170	180
7	2320	2500	140	130	86	140
8	2420	2240	120	120	100	210
9	2520	1980		179	240	100
10	2430			64	170	82
11	2140				64	20
12	2100				160	160
13						160
Minimum	2100	640	76	28	64	20
Maximum	2520	2610	370	179	300	220
Median	2355	2180	145	115	145	140
Mean	2322	2077	174	100	161	134
StdDev(n-1)	146	582	98	45	81	57

Table 39: Extractable iron concentration (ppm) in surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	59	51	150	56	73	80
2	57	51	76	74	74	80
3	60	50	75	72	72	81
4	51	116	73	64	71	72
5	53	61	70	54	71	81
6	57	45	72	66	49	80
7	60	57	74	66	71	80
8	55	47	74	71	66	79
9	63	50		69	71	81
10	49			53	71	75
11	57				57	41
12	56				79	78
13						75
Minimum	49	45	70	53	49	41
Maximum	63	116	150	74	79	81
Median	57	51	74	66	71	80
Mean	56	59	83	65	69	76
StdDev(n-1)	4	22	27	8	8	11

Table 40: Extractable manganese concentration (ppm) in surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	27.0	32.0	40.0	20.0	33.0	29.0
2	25.0	32.0	26.0	33.0	33.0	33.0
3	32.0	33.0	33.0	29.0	33.0	25.0
4	29.0	62.0	34.0	22.0	34.0	34.0
5	29.0	31.0	30.0	14.0	34.0	18.0
6	29.0	16.0	32.0	33.0	31.0	17.0
7	32.0	33.0	31.0	31.0	33.0	9.4
8	29.0	33.0	37.0	32.0	33.0	19.0
9	28.0	33.0		33.0	33.0	21.0
10	31.0			18.0	33.0	32.0
11	27.0				33.0	5.4
12	25.0				34.0	25.0
13						30.0
Minimum	25.0	16.0	26.0	14.0	31.0	5.4
Maximum	32.0	62.0	40.0	33.0	34.0	34.0
Median	29.0	33.0	32.5	30.0	33.0	25.0
Mean	28.6	33.9	32.9	26.5	33.1	22.9
StdDev(n-1)	2.4	11.9	4.3	7.3	0.8	9.0

Table 41: Extractable sulphate concentration (ppm) in surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	>20.0	>20.0	>20.0	0.4	>20.0	>20.0
2	>20.0	>20.0	>20.0	7.2	>20.0	>20.0
3	>20.0	>20.0	2.8	8.0	>20.0	>20.0
4	>20.0	>20.0	4.8	>10.0	>20.0	6.6
5	>20.0	>20.0	>20.0	3.6	>20.0	>20.0
6	>20.0	>20.0	>20.0	7.0	>20.0	9.4
7	>20.0	>20.0	>20.0	3.6	>20.0	8.6
8	>20.0	>20.0	4.6	6.4	>20.0	5.6
9	>20.0	>20.0		>10.0	>20.0	4.6
10	>20.0			>20.0	>20.0	3.8
11	>20.0				1.6	3.0
12	>20.0				>20.0	>20.0
13						>20.0
Minimum	>20.0	>20.0	2.8	0.4	1.6	3.0
Maximum	>20.0	>20.0	>20.0	>20.0	>20.0	>20.0
Median	>20.0	>20.0	>20.0	7.1	>20.0	9.4
Mean	20.0*	20.0*	14.0*	7.6*	18.5*	12.4*
StdDev(n-1)	0*	0*	8.3*	5.3*	5.3*	7.5*

Table 42: Visual carbonate content estimate of surficial sediment samples collected from study ponds (25-26 September, 1985). VL = very low, L = low, M = medium, A = abundant See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	M	L	A	A	A	A
2	M	L	A	A	A	A
3	VL	L	A	A	A	A
4	L	L	A	A	A	A
5	L	A	A	A	A	A
6	L	L	A	A	A	A
7	L	L	A	A	A	A
8	L	L	A	A	A	A
9	L	VL		A	A	A
10	M			A	A	A
11	VL				A	A
12	VL				A	A
13						A

Visual estimation of the relative carbonate content was assessed by the degree of effervescence noted after treatment of a dried sediment sample with dilute (ca. 4N) HCl. Except for the site 5 sample from Raspberry Pond (Figure 19), carbonate content was generally low to very low in Spruce and Raspberry (Table 42). In contrast, carbonates were abundant in all sediment samples collected from Pine, Golden, Hike and Birch Ponds. Quantitative analyses of HCO_3^- and CO_3^{2-} concentrations of these samples were not, however, performed.

Macronutrients

Extractable nitrate concentrations of Spruce Pond sediment samples (1.4-4.4 ppm; mean = 3.0 ppm) were similar to concentrations in Raspberry Pond samples (1.4-4.0 ppm; ppm = 2.8 ppm) (Table 43). Nitrate levels were ca. 2 ppm lower in samples from Pine Pond except for a high value (27.4 ppm) at site 1 (Figure 26). Ranges of concentration were similar for Golden Pond (0.8-2.8 ppm) and Hike Pond (0.6-3.4 ppm) samples and slightly lower in Birch Pond samples (0.4-1.2 ppm).

The highest sediment extractable phosphorus levels were found in samples from Pine Pond (9.6-50.8 ppm; CV=39%). Samples from individual sites in Golden, Hike and Birch Ponds contained as much as 26-40 ppm (Table 44). However, mean P was 4-5 ppm lower in Golden Pond (mean 13.4 ppm; CV=55%) than in Hike Pond (18.9 ppm; CV=58%) or Birch Pond (17.9 ppm; CV=56%). Levels of extractable-P in Spruce Pond and Raspberry Pond were similar (means 5.8 ppm and 5.3 ppm respectively) and lower than those of all other pond samples (Table 44).

Other Components

Organic matter (OM) content (30% H_2O_2 digestion) of all sediment samples was < 10% bulk dry weight (Table 45) except for samples from sites 1 (33.3%) and 3 (34.7%) in Pine Pond, which contained visually large amounts of allocthanous plant litter (eg. tree leaves etc.). Other samples from Pine Pond contained smaller amounts of litter, although median OM (5.5%) was higher than in other ponds (0.9-4.0%). Organic matter of Raspberry Pond sediment samples was consistently < 2% and was notably low (0.7-0.8%) among bordering Typha spp. beds. Gravelly samples collected from sites 1,5 and 10 of Golden Pond (Figure 21) contained less organic matter (0.5-1.7%) than samples from other sites (2.0-5.3%) which contained varying amounts of decaying plant litter.

In the three largest ponds (Spruce, Hike and Birch--Table 3), there was evidence of spatial distribution of organic matter. Although Spruce Pond sediment samples were generally low in organic matter (mean 1.9%) in relation to all ponds but Raspberry, samples collected from the pond periphery (sites 1,3,6-7,9,11-12)(Figure 18), particularly those collected from among beds of Typha spp. (sites 1 and 11), contained more organic matter (> 2%) than those in the pond center (0.8-1.7%). Samples from the southern, southwestern and northeastern extremities of

Table 43: Extractable nitrate concentration (ppm) in surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	4.4	3.2	27.4	0.8	1.6	1.2
2	3.4	4.0	1.6	1.6	1.0	1.2
3	2.6	2.6	0.6	2.0	0.6	1.2
4	4.0	3.6	0.6	1.4	0.6	1.2
5	2.4	1.4	0.8	2.2	0.8	1.2
6	2.6	2.8	0.8	1.4	3.4	1.2
7	2.4	2.4	0.6	2.2	1.0	1.0
8	3.0	3.2	0.8	1.6	0.8	1.2
9	1.4	2.2		2.0	2.0	0.4
10	4.0			2.8	1.2	0.6
11	3.0				1.0	0.4
12	3.0				1.0	1.0
13						1.0
Minimum	1.4	1.4	0.6	0.8	0.6	0.4
Maximum	4.4	4.0	27.4	2.8	3.4	1.2
Median	3.0	2.8	0.8	1.8	1.0	1.2
Mean	3.0	2.8	4.2	1.8	1.3	1.0
StdDev(n-1)	0.8	0.8	9.4	0.6	0.8	0.3

Table 44: Extractable phosphorus concentration (ppm) of surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	8.2	5.0	34.2	2.4	15.2	12.0
2	4.8	9.8	28.2	16.4	31.2	6.6
3	5.4	2.8	31.2	15.8	40.0	9.6
4	8.6	12.4	23.6	9.0	17.8	10.6
5	6.8	5.2	34.8	9.2	26.8	9.8
6	4.4	1.2	9.6	26.4	5.8	22.8
7	4.2	5.4	50.8	21.8	21.2	28.6
8	3.4	4.6	28.6	15.0	8.0	33.0
9	8.0	1.6		13.4	8.8	25.0
10	8.2			4.6	28.0	19.4
11	3.0				5.4	1.4
12	4.8				18.4	28.4
13						26.0
Minimum	3.0	1.2	9.6	2.4	5.4	1.4
Maximum	8.6	12.4	50.8	26.4	40.0	33.0
Median	5.1	5.0	29.9	14.2	18.1	19.4
Mean	5.8	5.3	30.1	13.4	18.9	17.9
StdDev(n-1)	2.0	3.7	11.6	7.4	11.0	10.1

Table 45: Organic matter content (% dry weight) of surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	3.3	1.3	33.3	0.5	6.8	8.5
2	1.4	0.6	5.9	5.3	1.3	3.4
3	2.0	0.8	34.7	6.0	1.8	4.0
4	1.4	1.3	2.6	4.2	1.6	8.8
5	0.8	0.9	6.6	0.8	1.6	4.8
6	2.0	0.7	5.0	2.0	1.7	4.4
7	2.4	1.6	3.5	1.8	4.0	3.7
8	1.7	1.2	2.4	3.6	0.9	3.8
9	3.8	0.8		5.1	3.6	1.8
10	0.9			1.7	2.4	1.5
11	2.0				0.6	0.3
12	1.6				6.0	4.6
13						5.7
Minimum	0.8	0.6	2.4	0.5	0.6	0.3
Maximum	3.8	1.6	34.7	6.0	6.8	8.8
Median	1.9	0.9	5.5	2.8	1.8	4.0
Mean	1.9	1.0	11.8	3.1	2.7	4.3
StdDev(n-1)	0.9	0.3	13.8	2.0	2.0	2.4

Table 46: Extractable copper concentration (ppm) in surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	14.0	14.0	19.0	3.8	14.0	0.76
2	15.0	14.0	4.1	11.0	7.4	2.7
3	20.0	14.0	5.1	11.0	8.7	1.9
4	13.0	20.0	8.9	4.8	9.5	0.08
5	14.0	9.4	2.8	3.9	14.0	1.6
6	17.0	7.0	7.4	7.9	4.3	1.1
7	20.0	14.0	2.0	9.3	16.0	2.1
8	17.0	12.0	5.4	10.0	9.7	1.9
9	13.0	10.0		13.0	12.0	6.7
10	15.0			6.1	12.0	4.1
11	17.0				4.4	0.65
12	15.0				4.8	1.4
13						0.67
Minimum	13.0	7.0	2.0	3.8	4.3	0.08
Maximum	20.0	20.0	19.0	13.0	16.0	6.7
Median	15.0	14.0	5.3	8.6	9.6	1.6
Mean	15.8	12.7	6.8	8.1	9.7	2.0
StdDev(n-1)	2.4	3.7	5.4	3.3	4.0	1.8

Hike Pond (sites 1,7 and 12--Figure 22) contained more organic matter (4-6.8%) than sites in the central portions of the basin (0.6-1.8%)(Figure 16). Samples from Birch Pond contained 3.4-8.8% OM except for samples from the centrally located sites 9-11 (site 11 being largely coarse sand), where organic matter was comparatively low (0.3-1.8%).

Analyses of sediments for extractable copper (Table 46) indicated that levels were higher in Spruce Pond (13-20 ppm) and Raspberry Pond (7-20 ppm) than in the remaining four ponds (Pine - 6.8 ppm; Golden - 8.1 ppm; Hike - 9.7 ppm; Birch - 2.0 ppm), although individual samples in Pine, Golden and Hike Ponds were within these ranges (19, 13 and 16 ppm respectively). Samples from the central sites (9,10) in Birch Pond contained higher copper than remaining sites, which were all lower (0.08-2.7 ppm) than detected in other ponds.

Extractable zinc analyses (Table 47) were variable between sites in each pond (CV 30-129%). Spruce Pond data were generally higher than those of other ponds (minimum 1.4 ppm versus minima of 0.10-0.32 ppm) except for high concentrations at sites 1 and 6 (6-6.3 ppm) in Pine. Median values were slightly lower in Hike Pond (0.6 ppm) and Birch Pond (0.3 ppm) than in the other four ponds (0.9-2.2 ppm).

4.0 Discussion

4.1 Preliminary Pond Evaluation

Ponds were selected for this study with the objective of minimizing their chemical, physical and biological dissimilarity (Goldsborough & Brown 1986). Several features of the six chosen ponds led us to believe that they would meet this objective. First, all ponds are within a 12 km radius and four of the six are within one kilometre. All ponds overlie Precambrian granite and gneiss (Weir 1960), and geological discontinuities over this small distance were assumed to be minimal. The overburden is relatively thin at all sites and consists of coarse sand and gravel overlain by an organic soil layer which in places is < 10 cm thick. Much of the soil horizon was removed from around Golden, Pine and Hike Ponds, presumably a result of excavation activity, and has not been reestablished. Bedrock protrusions are evident along the shores of Hike and Birch Ponds, and outcroppings can be seen adjacent to all others. These features were taken as indicators of chemical and hydrological uniformity of the respective watersheds.

Second, the basins were all excavated at approximately the same time (1958-1959) during construction of the nearby provincial highway. Since then, all have become filled with water, colonized by submergent and emergent aquatic plants and surrounded by deciduous and coniferous forest (Goldsborough & Brown unpubl.). The chronology of these events cannot be established accurately because the exact dates of basin abandonment and rates

Table 47: Extractable zinc concentration (ppm) in surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	2.3	1.8	6.3	0.18	2.6	1.0
2	1.9	1.7	1.3	1.5	0.50	3.4
3	2.7	1.2	0.88	2.8	0.48	1.2
4	2.1	3.0	1.4	1.0	0.65	0.26
5	1.8	0.66	0.63	0.36	0.55	0.52
6	2.4	0.67	6.0	0.56	1.0	0.20
7	4.3	2.6	0.32	0.59	0.93	0.30
8	2.5	1.2	1.0	1.1	0.48	0.16
9	2.1	0.28		1.4	1.4	1.1
10	2.5			0.88	0.61	0.56
11	1.9				0.28	0.33
12	1.4				0.38	0.17
13						0.10
Minimum	1.4	0.28	0.32	0.18	0.28	0.10
Maximum	4.3	3.0	6.3	2.8	2.6	3.4
Median	2.2	1.2	1.2	0.9	0.6	0.3
Mean	2.3	1.5	2.2	1.0	0.8	0.7
StdDev(n-1)	0.7	0.9	2.4	0.8	0.6	0.9

of infilling are unknown, although it was assumed that these processes proceeded similarly in all ponds.

Third, results of an initial survey, which were later corroborated by morphometric soundings, showed that the ponds are relatively shallow (<4m maximum depth). This limits the formation of thermal and possibly chemical stratification to quiescent periods and permits wind-induced mixing of the water column. Therefore, spatial variability of water chemistry and ensuing effects on biological productivity within any given pond would likely be low.

Finally, all ponds are headwater ponds with no visible overland discharge at the time of the primary survey in early 1985. This minimizes effects of influent water on pondwater chemistry. Moreover, the lack of water throughput simplifies the potential fates of applied herbicide during subsequent manipulation.

4.2 Pond Comparison Method

The overall objective of this study is to examine changes in chemical and biological characteristics of the study ponds in response to glyphosate additions (Goldsborough & Brown 1986). Three ponds will receive herbicide treatment in 1986 and subsequent pond monitoring may permit quantification of changes in the chemical, physical or biological parameters:

1. in herbicide-treated ponds relative to baseline (1985-1986) data for those ponds, and

2. in herbicide-treated ponds relative to untreated control ponds at the same time (1986-1987).

All available data describing the chemical and physical environment of the ponds in 1985 are tabulated in the present report and data analyses provided here are preliminary. Further analyses will be published elsewhere and in future project documentation.

Despite the factors listed above which assumed pond uniformity, the present data show that marked differences between the ponds exist for many of the measured parameters. Therefore, to permit the second comparison above, a blocked experimental design for the assignment of herbicide treatment to particular ponds was chosen. This necessitated the identification of three pairs of ponds which were sufficiently similar, chemically and biologically, so that one member of each pair could receive treatment while the other remained an untreated control. Similarities between all possible pond pairs, based on characteristics of water and sediment, were assessed using the Euclidean distance function (Gauch 1982):

$$D_{JK} = \left(\sum_{I=1}^{N} (X_J - X_K)^2 \right)^{1/2}$$

where D is the dissimilarity (distance) between ponds J and K, I is a parameter used in comparison (eg. specific ion concentration), N is the total number of parameters and X is a given observation for I in J or K relativized to a common scale (0-100) as follows:

$$X = \frac{(X_I - X_{MIN})}{(X_{MAX} - X_{MIN})} \times 100$$

Relativization assured that each parameter received equal emphasis. Datasets used in calculations are tabulated in Appendices FF (water) and HH (sediment). The former consisted of mean data for all available physical and chemical parameters of sampled water (flagged by asterisks where necessary to indicate the inclusion of '<' or '>' values). Related parameters (eg. calcium/magnesium and hardness) were excluded. The sediment dataset consisted of median values to account for the extreme spatial heterogeneity found for selected parameters in some ponds.

Pondwater and sediment characteristics were used separately to produce two Euclidean distance matrices. The rationale for this separation was that although interactions presumably exist between the sediments and overlying water, the respective data, and their summary statistics were not expressed on an equal temporal scale. Whereas water data are available from May to December, all sediment characterizations are based on one series of samples collected in September.

Euclidean distance matrices were used as input for hierarchical, agglomerative cluster analyses using an unweighted arithmetic averages algorithm (Orlóci & Kenkel 1984). The output of these analyses were tree dendrograms depicting the grouping of ponds into clusters with similar ponds clustering more closely than relatively dissimilar ponds. Results are presented in Figure 26 (water) and Figure 27 (sediment).

4.3 Pond Blocking

A consistent feature of both dendrograms is the separation of Spruce and Raspberry Ponds from Hike, Pine, Golden and Birch Ponds (Figures 26-27). In the case of the water dataset, the former ponds appear as distinct branches from the remaining ponds; Pine and Birch Ponds form one discrete cluster, and Golden and Hike Ponds form another cluster. Sediment samples from Spruce and Raspberry Ponds cluster together, while the other four ponds form one large cluster with Pine and Hike Ponds, and Golden and Birch Ponds forming two minor subgroupings.

The basis for the segregation of Spruce and Raspberry Ponds from all others is due largely to the fact that the concentrations of most major ions, notably calcium and magnesium, were consistently highest in these ponds. Despite the magnitudinal differences, the relative proportions of all ions were nearly the same (Figure 25; $Ca = Mg > Na > K$; $HCO_3 >> SO_4 >> Cl = CO_3$ for anions on a milliequivalent basis). The importance of sulphate

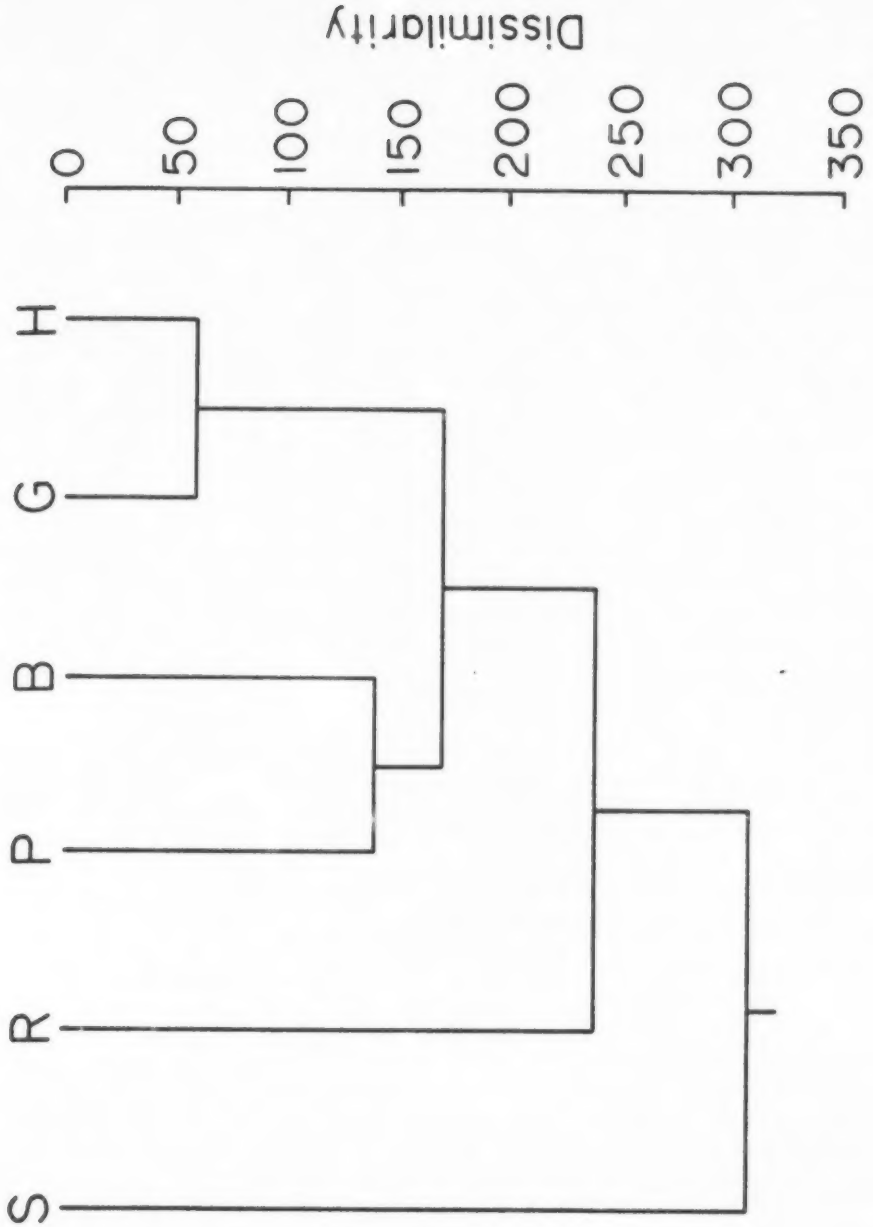

Figure 26: Tree dendrogram representing the Euclidean dissimilarities between pairs of ponds based on seasonal mean water chemistry and physics (Appendix FF).

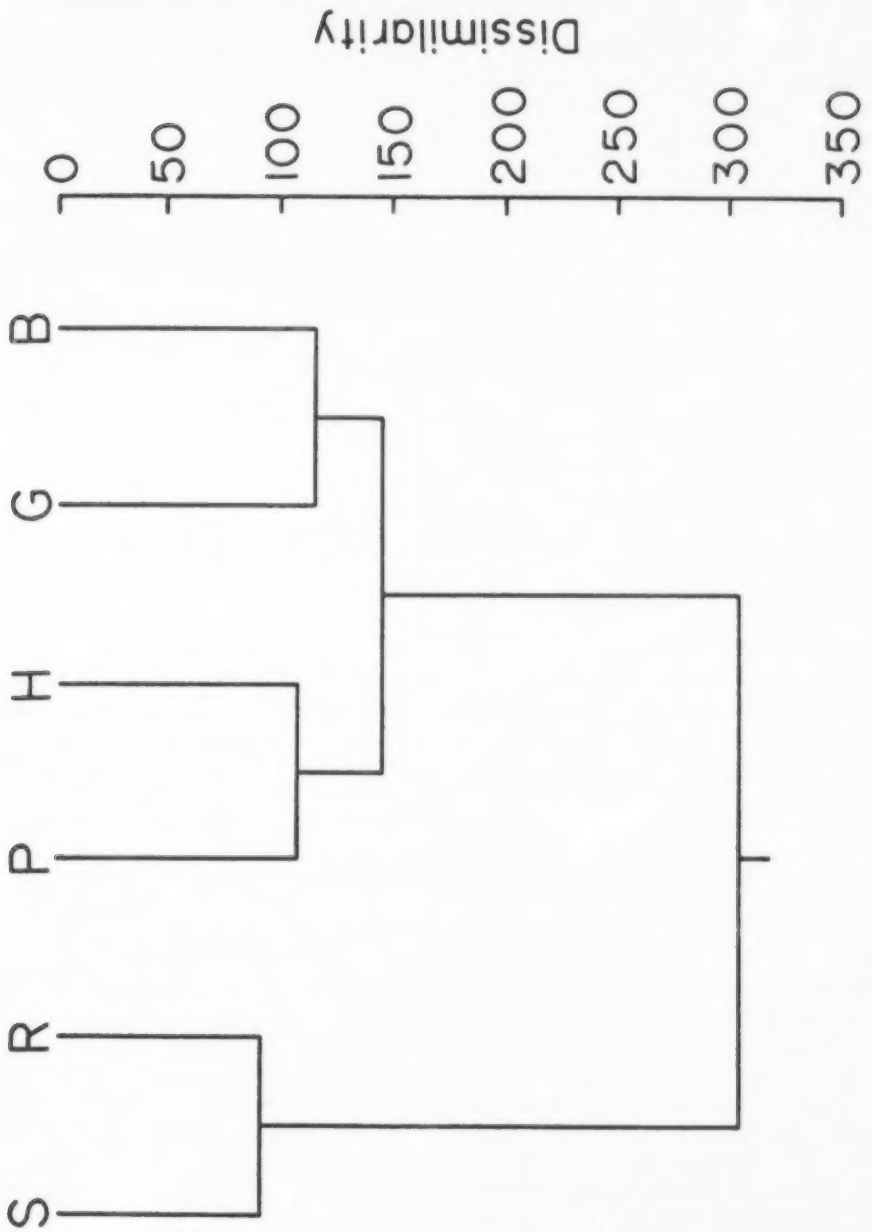

Figure 27: Tree dendrogram representing the Euclidean dissimilarities between pairs of ponds based on median sediment chemistry and texture (Appendix HH).

to the ion balance was greater in Spruce and Raspberry Ponds (similar to Pine and Birch) than in Golden and Hike Ponds.

The characteristics of the sediments of Spruce and Raspberry Ponds also distinguished them from the other study ponds. Like their respective water columns, the sediments of these two ponds contained larger amounts of all major cations (Ca, Mg, Na, K) and nitrate but less phosphate and organic matter than the other four ponds. Texturally, Spruce and Raspberry Pond sediments were comprised of proportionately finer particles (clay-size) and were more spatially homogenous (less variability between samples) than in other ponds. A possible connection between sediment texture and sediment and water chemistry may have bases in the mineralogical composition of the sediment. A similar relationship has been postulated for Crowduck Lake in Whiteshell Provincial Park which contained a predominantly clay sediment (60-100%) and enclosed more chemically enriched water than other nearby lakes (Hagenson & O'Connor 1978b).

The low organic matter content of the sediments of Spruce and Raspberry Ponds did not visually appear to be caused by lower autochthanous primary production. The aquatic macrophyte Myriophyllum exalbescens covered the entire basin floor of Spruce Pond throughout much of the summer, and both ponds supported large littoral stands of Typha spp.. While there was some evidence that organic matter was higher around the pond periphery of the largest ponds (Spruce, Hike and Birch), the differences were comparatively small and were not seen in Raspberry Pond, where sediment samples collected from within Typha stands did not contain consistently more organic matter than those collected from the center of the basin. One of at least two factors could contribute to these observations. Although there are no substantiating data, Spruce and Raspberry Ponds could be comparatively younger than the other ponds and have therefore accumulated less organic sediment. Alternately, the lack of organic matter could be related to relatively low inputs of particulate terrestrial organic matter. In late autumn, leaves of overhanging deciduous trees carpeted the water surface and the pond bottom of Pine, Golden, Hike and Birch Ponds. Detrital material in the form of partly decomposed leaves and aquatic plants was visibly abundant in surficial sediment samples collected from these ponds in late September. By contrast, Spruce and Raspberry Ponds are surrounded by shrubs which did not generally shed leaves on the pond surface. Sediment samples collected from these ponds contained no obvious decaying plant litter.

Despite the above similarities, significant chemical and physical differences were found between Spruce and Raspberry Ponds. As shown by cluster analyses, these differences were largely manifested in their water rather than their sediments. For instance, the water in Raspberry Pond was comparatively less alkaline and contained higher concentrations of total iron, manganese, silica and DOC than the water of Spruce Pond. Further, light penetration into Raspberry Pond (as measured by Secchi disk depth) was low due to its extremely colored water. These differ-

ences likely resulted from the fact that while Spruce Pond had no obvious overland water input, aside from runoff during precipitation, Raspberry Pond intermittently received direct drainage from an adjacent low-lying area of moss, sedges, fallen trees and debris which retained water through much of the summer. Incompletely decomposed terrestrial organic matter (humic and fulvic acids, humin and low molecular weight organic compounds--Stumm & Morgan 1981) from the adjacent wetland probably contributed to Raspberry Pond's dissolved (dissolved plus colloidal) organic carbon (DOC) load during irregular periods of discharge.

Stewart & Wetzel (1981) reported that input of inorganic and dissolved humic materials to Lawrence Lake, Michigan, followed periods of intense rain. In the present context, inorganic materials associated with allochthanous "spike" inputs are likely to be important to pond nutrient budgets due to the small pond basin size and enclosed water volume. This can be seen from the rapid changes in water chemistry of Raspberry Pond corresponding to a major water input resulting from heavy rainfall during 12-19 August. Measurements of pond level taken before and after the rain (Table 2) are underestimates of total water receipt by Raspberry Pond, since outflow was not taken into account. Following this input, levels of iron, TKN and silica increased, while sodium, calcium, magnesium, alkalinity, pH and conductivity decreased. All changes are consistent with an input of acidic (mineral or organic), Ca/Mg-poor, DOC-rich water. Prior to this addition, conductivity, pH and alkalinity increased along with concentrations of sodium, calcium and magnesium, while pond level decreased. Notably, these parameters also increased with time following the August water input.

A working hypothesis is that the water chemistry of Spruce Pond is influenced primarily by varying contributions of solutes in groundwater discharge, wet- and dryfall inputs and sediment/water exchange, while that of Raspberry Pond is further modified according to the quantity of allochthanous inputs. This would explain the finding that sediments of Spruce and Raspberry Ponds cluster closely together while their respective waters do not (Figures 26-27).

While the sediments of Spruce and Raspberry Ponds were texturally homogenous, samples collected at various sites within all other ponds showed little consistency. For example, one sample from Birch Pond consisted almost entirely of sand, while other samples from nearby sites consisted of approximately one third silt and clay particles (Figure 23). The four southern ponds were alike only in the sense that spatial variability masked any systematic differences in both sediment texture and chemistry which may exist at particular microsites on the pond bottoms. As a result, while Pine, Golden, Hike and Birch Ponds clustered together (Figure 27) on the basis of lower pH and conductivity, lower concentrations of major cations and nitrate, and higher phosphorus content than samples from Raspberry and Spruce Ponds, no significant differences between individual ponds were apparent.

The overlying waters of the four southerly ponds were separated into two clusters which appeared to segregate from Spruce and Raspberry Ponds largely as a result of their lower overall ionic strength. On the basis of field observations, similarities in these four ponds seemed to be due largely to chemical rather than physical properties since Golden Pond (and Hike Pond to a lesser extent) shared the high water clarity (high Secchi disk depth, low water color) which characterized Spruce Pond rather than the intense color which typified Pine and Birch Ponds. Chemically, the waters of Golden and Hike Ponds were more acidic (pH 6.90-8.55) than that of Spruce Pond but were less so than Raspberry, Pine and Birch Ponds. Specific conductance and calcium concentrations were intermediate in Golden and Hike Ponds as compared to high values reported for Spruce and Raspberry Ponds and low values for Pine and Birch Ponds. Other similarities between Golden and Hike Ponds included total iron, sulphate, TKN and DOC concentrations, which tended to be among the lowest of all ponds sampled. At the same time, these ponds differed in concentrations of magnesium, sodium, fluoride and silica, which were usually greater in Hike than in Golden Pond. Alkalinity was also slightly lower in Golden Pond as compared to Hike Pond throughout the summer. These differences were generally of lower magnitude than chemical differences distinguishing them from Pine and Birch Ponds which, in addition to their moderate water color, were the most chemically dilute of all sampled ponds.

The proposed pond blocking for future manipulative studies is as follows:

Block	Treated Pond	Control Pond
1	Spruce	Raspberry
2	Birch	Pine
3	Hike	Golden

Spruce and Raspberry Ponds were paired because of their comparatively high chemical status in relation to the other ponds. The choices of the constituent ponds in the latter two pairs are based primarily on results of the cluster analyses of water parameters because this would relate more directly to biological productivity in the respective ponds than features of the sediments. Tentatively, it is suggested that Spruce, Birch and Hike Ponds receive herbicide treatment because all are headwater ponds and are large enough to facilitate low-level aerial herbicide application.

4.4 Comparison with other Ponds in the Study Area

During a primary survey of the study area on 13-14 May, 1985, four additional ponds were sampled for possible inclusion in this study. Like the present six study ponds, these ponds are borrow pits and appear to be of similar age and morphometry. Three ponds, designated C, D and F are located within 0.5 km of Raspberry Pond. Pond C is located immediately to the east of

Raspberry Pond and discharges into it during periods of high water. Ponds D and F are located west of Raspberry Pond on the opposite side of highway 304 and are irregularly connected to each other and to an adjacent drainage channel. Surface water samples from these ponds were analyzed (Table 48), and the results agree closely with corresponding data from Raspberry Pond. It is therefore likely that all ponds are subject to wetland drainage as has been hypothesized for Raspberry Pond.

Pond Z is located a few hundred meters northwest of Golden Pond and is surrounded by dense deciduous vegetation with no visible inflow or outflow. Chemical and physical properties of its water (Table 48) are similar to those of Golden and Hike Ponds.

The similarities between the four additional ponds and the two study ponds nearest to them indicates that the study ponds may be typical within the study area, but the pronounced chemical and physical differences between the waters of Pine and Golden Ponds, which are separated by less than 100 meters distance, argues against such broad generalization. Pondwater chemistry is instead subject to various local influences, and this supports the need to include several ponds in toxicological assessments.

4.5 Pondwater Inputs/Outputs

The present data are inadequate to produce a hydrologic budget for the study ponds. However, qualitative information exists relative to several components of the budget. In addition to direct precipitation input, it is clear that watershed input also occurred in all ponds. First, the increase in water levels of Pine and Golden Ponds in mid-August exceeded the amount contributed by surface precipitation alone. The importance of such inputs to the study ponds was dramatic; pond volume increased from 9% (Spruce) to 56% (Pine) within 7 days of a single input event. Second, inputs of compounds such as silica, which are generally absent in precipitation, must originate in the watershed. Brunskill et al. (1971) found that materials comprising the glacial drift at the Experimental Lakes Area (ELA) of northwestern Ontario include silica-rich quartz, plagioclase and K-feldspar sands and gravel. It is likely that the material in the Pine Falls area is of similar composition. Preliminary calculations of the silica input occurring between 12 and 19 August based on observed silica levels and estimated pond volumes show that inputs were well correlated ($r=0.92$) with the pond surface area (Table 49) for ponds which did not have discernable outflow (excludes Raspberry Pond).

Although changes in the water chemistry of Raspberry Pond during the period 12-19 August were extreme, detectable chemical changes accompanied water input to all ponds. These included increases in total iron concentration in Pine and Birch Ponds, and sulphate concentration in Pine Pond. These changes were inconsistent between ponds, however, and were not manifested in all measured parameters. For example, there was no systematic

Table 48: Selected water chemical and physical data for ponds sampled during a primary survey (13-14 May, 1985).

Parameter	Pond C	Pond D	Pond F	Pond Z
Secchi depth (m)	0.70	1.20	1.05	2.00
Color (Pt)	>50	>50	>50	15
Conductivity (uS/cm)	70.6	168.0	199.0	147.0
pH	6.55	7.65	7.25	7.40
Sodium (mg/L)	2.05	10.9	7.58	3.10
Potassium (mg/L)	<5.00	<5.00	<5.00	<5.00
Calcium (mg/L)	7.18	26.9	18.8	16.6
Magnesium (mg/L)	4.97	14.8	10.4	6.26
Iron (mg/L)	0.56	0.10	0.31	0.33
Manganese (mg/L)	0.07	0.05	0.18	<0.02
Tot.alkalinity (mg/L)	20.0	104.0	70.0	70.0
Chloride (mg/L)	3.0	6.0	5.0	4.0
Fluoride (mg/L)	<0.1	0.18	0.18	0.11
Sulphate (mg/L)	30	25	21	1.5
NH_3-N (mg/L)	0.02	<0.02	<0.02	<0.02
NO_3/NO_2-N (mg/L)	<0.01	<0.01	<0.01	<0.01
TKN (mg/L)	1.7	1.1	1.3	0.50
Tot.phosphorus (mg/L)	0.04	0.05	0.04	0.03
Silica (mg/L)	1.6	4.0	4.8	2.4
Ion error (%)	5.02	6.61	6.68	2.32

Table 49: Estimated silica input (g/m^2) to the six study ponds during the period 12-19 August, 1985.

Pond	Si pool (12/08) (g/m^2)	Si pool (19/08) (g/m^2)	Total Input (kg/pond)
Spruce	2.30	3.26	4.95
Raspberry	2.87	8.29	14.09
Pine	0.89	2.76	3.72
Golden	0.38	1.44	3.13
Hike	1.99	3.49	9.50
Birch	1.29	3.02	13.23

Table 50: Seasonal mean water color (Platinum-cobalt units) of the six study ponds (1985) based on extrapolation from Secchi disk depth (m) using the formula of Eloranta (1978): log(color) = (log(Secchi) - 1.2440)/-0.57; * - includes '>' data

Pond	Seasonal Mean Secchi depth (m)	Observed Color (Pt)	Estimated Color (Pt)
Spruce	2.60*	16	28
Raspberry	0.62	50*	352
Pine	1.01	49*	150
Golden	2.46*	11	31
Hike	1.88	8	50
Birch	1.41	50*	83

change in total phosphorus levels in any pond in this period.

In the absence of direct surface outflow, hydrologic output from the ponds was restricted to groundwater recharge and evapotranspiration. Neither process was quantified directly but the nearly linear decrease in pond level between early July and mid-August (Figure 10) corresponded to the most intense period of plant growth, maximum air temperature and low relative humidity (Figure 2). Estimates of potential evapotranspiration calculated from air temperature using the method of Thornthwaite (1948) increased from June (8.5 cm) to a maximum in July (11.5 cm), and decreased in August (9.8 cm) and September (6.6 cm). Transpirational losses by emergent plants and direct evaporation from the pond surfaces cannot be solely responsible for decreasing pond level because ponds with the smallest and largest surfaces areas (Pine and Birch Ponds respectively) experienced the greatest drawdown and none of the three most severely drained ponds supported large littoral plant stands. This suggests that fluctuations in the water table may largely account for observed water supply. Additionally, groundwater discharge may explain the varying response of pond water level to the August input and the subsequent change in level through to October (the level of Golden Pond, for example, continued to increase while Birch Pond remained nearly constant). Data quantifying the respective elevations of the ponds and their orientation to the water table are not available.

4.6 Pond Dystrophy and Related Chemical Considerations

Raspberry, Pine and Birch Ponds were distinguished from Spruce, Golden and Hike Ponds by their extremely colored water and low Secchi disk depth. Raspberry was the most heavily stained of the three ponds although analytical limitations did not permit quantification of this trend. Using the empirical formula of Eloranta (1978), which related the Secchi disk depth of several dystrophic Finnish lakes to their color, estimates of actual pond color in the study ponds were derived (Table 50). Due to the lack of definition of Secchi disk depth in Spruce and Golden Ponds, which often exceeded total pond depth, estimates of water color in these ponds were greater than the observed values (Table 50). Moreover, insensitivity of the formula to changes in Secchi disk depth caused by factors unrelated to water color (eg. phytoplankton blooms, turbidity etc.) resulted in severe overestimation of the color of Hike Pond water. Despite these qualifications, estimates of water color in Raspberry, Pine and Birch Ponds related well to perceived differences between them.

The dichotomy between the colored and uncolored pond triplets was not well differentiated by the present cluster analyses, which discriminated Raspberry Pond from Pine and Birch Ponds on the basis of its higher overall ionic strength. On a relative basis, however, the similarities between these three ponds were noteworthy. As suggested earlier for Raspberry Pond, this was probably a consequence of high humic acid content in Pine and Birch pondwater, for which there are several pieces of substan-

tiating chemical evidence. Most notably, the pH of colored pond waters (6.30-7.45) was lower than that of the comparatively uncolored ponds (6.90-8.65). As a result of ion exchange processes, humic waters are generally high in H^+. High levels of dissolved organic carbon (DOC), which were observed in Raspberry, Pine and Birch Ponds, have also been used as indicators of humic acid content (Eloranta 1978; Jackson & Hecky 1980; Arvola 1984). Although the clarity and high concentrations of calcium and magnesium of Spruce Pond water in conjunction with relatively high DOC argues against such a consistent correlation in the study ponds, the presence of uncolored humic compounds (cf. Shapiro 1964) or coprecipitation of humics by high concentrations of calcium and magnesium (Stumm & Morgan 1981) cannot be ruled out. In addition, DOC levels correlated directly ($r=0.88$) with absolute sulphate concentrations and the relative importance of sulphate to the ionic balance (Figure 43). Schindler & Bayley (unpubl.MS) have reported that sulphate may be exported from peatlands (along with humic material) into receiving waters as a result of high water throughput.

Pond dystrophy is probably attributeable largely to direct allochthanous input of terrestrial plant debris rather than autochthanous production (Wetzel 1983). Casual observations suggest that humification of leaf litter within the dystrophic ponds was not a significant contributor to the total DOC supply since Golden and Hike Ponds received large quantities of litter during autumnal leafdrop yet were comparatively uncolored and contain appreciably less DOC than neighboring colored ponds. Further evidence is seen in the coincidence of substantial water input and elevated DOC in Raspberry Pond.

Humic substances in the water column may have profound effects on pond water chemistry. For example, dystrophic ponds contained more iron than uncolored ponds (0.60-4.34 and <0.02-0.57 mg/L for the two groups of ponds respectively). This may be due to complexation of iron with humic compounds in the water column (Shapiro 1966; Stumm & Morgan 1981; Wetzel 1983) resulting in observed water color. Formation of humic complexes may also explain the relatively high levels of silica in Raspberry and Pine Ponds (Table 31). The ability of humic compounds to form colloidal complexes with inorganic compounds may also bear on the observation that total molybdate-reactive phosphorus levels were below analytical detection limits while total phosphorus levels were relatively high. An alternative explanation is that the majority of the total phosphorus pool (>99%) was in the form of organic phosphorus compounds throughout the sampling period. Similar explanations can be cited for the speciation of nitrogen compounds in the ponds, wherein total Kjeldahl levels greatly exceeded that present as ammonia, nitrite and nitrate.

Total titratable alkalinity of water from Spruce, Golden and Hike Ponds were consistently greater than corresponding estimates of total hardness based on the concentrations of calcium and magnesium in these samples. This suggests that hardness in these ponds was temporary and resulted from the formation of calcium

and magnesium carbonates (Wetzel 1983). At the same time, hardness estimates for the waters of colored ponds were often greater than observed alkalinity. This could be interpreted as evidence for 'non-carbonate' hardness (APHA 1980) due to the formation of Ca/Mg complexes with sulphate, chloride or nitrate, or it could mean that calcium levels were overestimated in humic water samples (M.P.Stainton pers.comm.). Calculations of ion balance error from total cation (Table 18) and anion (Table 26) concentrations are presented in Appendix EE. Normally, values less than or equal to 5% reflect acceptable accumulated analytical error (Golterman 1969). In the 1985 dataset, ion balance errors in excess of 10% were common in Raspberry Pond (seasonal mean 13%), Pine Pond (11%) and Birch Pond (12%) while those in Spruce, Golden and Hike Ponds were lower (5%, 5% and 4% respectively). In all cases, the discrepancy was the result of higher cation that anion totals and points either to the exclusion from the balance of a significant anion or overestimation of a cation (Golterman 1969).

Estimates of total dissolved inorganic carbon (DIC) are often made from measurements of pH and total alkalinity on the assumption that alkalinity in most waters is due to carbon dioxide, bicarbonate and carbonate in solution (eg. Golterman 1969). In humic waters, however, weak organic acids ($COOH^-$) may contribute to acid titrations for alkalinity. Therefore, reported alkalinity data for Raspberry, Pine and Birch Ponds (Table 19) probably overestimate alkalinity due to carbonates and supply of carbon for biological growth. Exclusion of organic anions from the ion balance may also explain part of the discrepancy noted above, particularly in light of the observation that ion balance error increased with the hypothesized input of humic materials to Raspberry Pond in August and remained at a higher level than found before the input (Appendix EE).

4.7 Comparison with other Precambrian Shield waters

To evaluate the degree of similarity of Pine Falls pondwater chemistry to that of natural water bodies, selected data describing the chemistry of lake epilimnia and major rivers on the southeastern (east of Lake Winnipeg) and northern (pre-impounded Southern Indian Lake, selected Flin Flon lakes) portions of the Precambrian Shield in Manitoba and northwestern Ontario (Experimental Lakes Area) were compiled (Table 51; Figure 28). The format of these data follows a similar tabulation presented in Armstrong & Schindler (1971) although it encompasses recent observations and is limited in geographic scope. Most of the available data comprise waters sampled during the summer and fall (May to October) although a few preliminary surveys of lakes in Nopiming and Whiteshell Provincial Parks have included water collections made during the late winter under ice cover (Brown, unpubl.data). These data probably do not encompass the possible range of chemical status at each sampling site, however, since some summary statistics are based on few values. The reported data are also based on varying analytical procedures which may bear on the comparability of different sources.

Table 51: Summary of water chemistry from selected water bodies on or near the Precambrian Shield in Manitoba and neighboring areas
* - includes 'C' data ; Loc.No. is the site number on accompanying map (Figure 28)

Location	Loc.No.	(ueq/L) Ca	Mg	Na	K	HCO_3	SO_4	Cl	(mg/L) Si	PO_4	NO_3/NO_2	TDP	TDN	Tot-Fe	Range pH	TDS mg/L	Cond. uS/cm	Month	Source
Ponds and Lakes																			
Pine Falls	1	459	732	378	<128	1424	194	<56	2.8	<0.001	<0.81	0.034	0.98	0.86	4.7-8.2	.	179	5-12	present study
Nopiming (*1)	2	280	412	<435	<51	315	184	<56	.	0.02	0.02	0.03	0.41	1.03	4.6-8.2	40	43	6-8	Hagenson & O'Connor 1978a
(*4)	2	.	.	.	.	385	.	.	.	.	0.12	0.025	.	0.39	4.2-7.1	.	50	2-3	D.J.Brown unpubl.
Whiteshell (*2)	3	754	582	<435	<51	1111	119	<56	.	.	0.22*	<0.02	.	.	4.5-8.6	77	100	6-8	Hagenson & O'Connor 1978b
(*5)	3	.	.	.	.	731	.	.	.	.	0.17	0.022	.	0.38	4.3-7.5	.	91	2	D.J.Brown unpubl.
S.E. Manitoba (*6)	-	.	.	.	.	1208	.	31	.	.	0.54	.	.	.	5.0-9.5	101	.	5-9	Pip 1985
E.L.A. (Ontario)	4	80	74	39	10	42	62	39	0.5	<0.001	<0.02	0.007	0.18	0.05	5.6-6.7	33	19	1-12	Armstrong & Schindler 1971
(*7)	4	80	58	39	7	.	75	14	1.0	0.002	0.01	0.005	0.24	0.09	5.2-7.7	.	19	6-8	Prokopowich 1979
Lake Winnipeg																			
north basin (center)	5	998-1498	798-1084	500	51	1999	400-800	401-499	*	.	.	.	.	.	.	.	200-300	6-10	Brunskill et al. 1979
south basin (center)	6	998-1996	400-1498	300-500	51-100	1500-1999	200-400	99-299	.	.	.	.	.	.	.	.	200-300	6-10	Brunskill et al. 1979
S.I.L. (Missi Falls)	7	618	412	135	31	885	67	34	2.1	0.002	0.02	0.012	0.4	.	7.4-7.8	53	103	1-12	Env.Can. 1978
Flin Flon (*3)	8	1378	1950	300	43	.	1016	592	.	.	.	.	.	.	4.8-9.1	.	500	1-12	McFarlane et al. 1979
Rivers																			
Winnipeg																			
Pointe du Bois	9	648	384	100	20	803	100	51	1.4	.	0.10*	0.019	0.48	0.17	6.8-8.4	52	106	1-12	Env.Can. 1980,82,84
Pine Falls	10	724	206	87	26	787	100	51	2.6	.	0.13*	0.030	1.06	0.34	7.2-7.5	54	100	2-8	Env.Can. 1980
Traverse Bay	11	438	248	78	20	829	300	45	.	.	.	.	.	.	7.2-7.9	.	97	6-10	Brunskill et al. 1979
Manigotagan																			
Hwy 304	12	464	264	52	20	541	92	31	1.4	.	0.04*	0.020	0.60	0.38	6.5-7.9	38	75	1-12	Env.Can. 1980,82,84
Berens & Pigeon																			
mouth	13	858	244	139	18	600	300	161	.	.	.	.	.	.	6.9-7.9	.	83	6-10	Brunskill et al. 1979

*1 Beresford, Birse, Black, Booster, Euclid, Flintstone, Manigotagan, Shoe, Springer, Tooth, Tulabi, Wallace
*2 Crowduck, Echo, George, Horseshoe, Meditation, Mud Turtle, Numao
*3 Beaverdam, Birch, Bluenose, Byklum, Cleaver, Cliff, Douglas, Embury, Flin Flon, Hasell, Hook, Johnson, Little Spruce, Maligne, Manistikwan, Neso, Nesootao, Otter, Phantom, Pothook, Ross, Precipice, Ruby, Schist, Scotty, Thompson, Twin, We, Whitehead, Winteringham, Wonderland,4,10,13
*4 Beresford, Bird, Black, Cat, Long, Shoe, Wallace, Manigotagan
*5 Betula, Big Whiteshell, Brereton, Caddy, Falcon, Jessica, Redrock, Star, West Hawk, White
*6 summary statistics for 100 unspecified lakes and ponds (44% of data) and rivers and creeks (see source for locations)
*7 103,114,126,129,223,224,226E,227,228,230,239,240,241,261,265,302N,302S,303,304,305,383,470

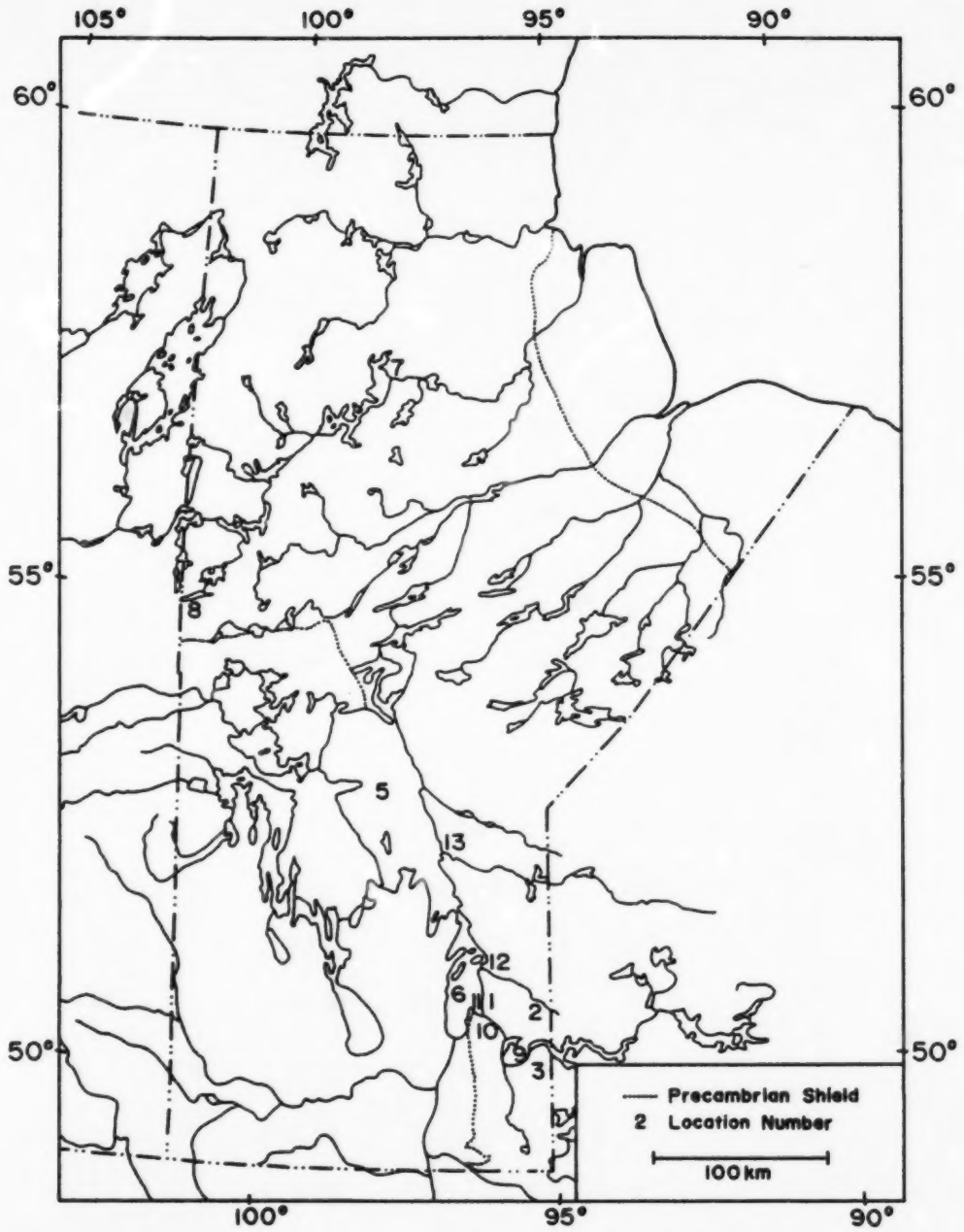

Figure 28: Locations of selected water sampling stations on the Precambrian Shield, Manitoba.

Measurements of specific conductivity are probably the least susceptible of all reported parameters to analytical error and the most illustrative of overall nutrient status. On these bases, they may provide the most reliable comparison (Armstrong & Schindler 1971). Seasonal mean conductivity of water in the Pine Falls ponds was slightly greater than in lakes in the Nopiming and Whiteshell Provincial Parks to the east and southeast of the study site respectively and in three major river systems flowing westward through the southeastern portion of the Precambrian Shield into Lake Winnipeg (Figure 28). At the same time, the pondwaters were more dilute than samples collected from the north and south basins of Lake Winnipeg (Table 51). However, this conclusion is misleading because it discounts the range of values observed between individual ponds. Therefore, values for Pine and Birch Ponds (ca. 45 uS/cm) were similar to those of the Nopiming lakes, slightly less than samples collected in Whiteshell lakes and in the cited rivers, and higher than lakes of the Experimental Lakes Area. Levels observed in Spruce Pond were generally higher than all other tabulated data (ca. 200 uS/cm higher than Lake Winnipeg) with the exception of a few lakes and creeks in the Flin Flon area (McFarlane et al. 1979). Raspberry and Hike Ponds were intermediate between these extremes.

The pH range of surface water samples collected from the study ponds was in close agreement with samples from most other areas on the Shield and varied from slightly below neutrality to moderately basic (Tables 10,51). The high values found consistently in Spruce Pond (ca. 8.0) were similar to some values from a site on the Winnipeg River at Pointe du Bois, a few samples collected in late summer from lakes in the Nopiming and Whiteshell areas and several unspecified sites between the Winnipeg and Manigotogan Rivers (Pip 1985).

Although the intercomparability of ion chemistry data may be questionable, some basic correspondences are seen (Table 51). Calcium and magnesium were the dominant cations (>75% total cationic strength) at all sites on a milliequivalent basis. Mean calcium levels of the Pine Falls ponds were within 200 ueq/L of data reported for Whiteshell lakes (Brown, unpubl.data), Southern Indian Lake and river flow in the Winnipeg, Manigotogan and Berens River systems (Table 51) while magnesium levels were ca. 200-500 ueq/L higher in the study ponds than at the latter sites. Sodium constituted approximately 20-25% of total cations in the Pine Falls ponds, at the ELA, in Southern Indian Lake and in Lake Winnipeg but only about 10% in Flin Flon lakes and in samples of river water (Table 51). Absolute sodium levels of Pine Falls pondwaters (ca. 370 ueq/L) were nearly the same as Lake Winnipeg water and more northern Shield lakes, but were greater than in river water. Comparisons of cation concentrations in individual study ponds were commensurate with comparisons to other water bodies based on specific conductance. The low levels of potassium detected in water at the ELA (7-10 ueq/L) and at northern Shield sites (31-43 ueq/L) explain the present finding that potassium was consistently below analytical detection in all ponds (Table 12).

At the pH prevailing in waters of the Precambrian Shield (Table 10,51), carbon speciation will favor free carbon dioxide and bicarbonate (Table 20-22; Golterman 1969). Therefore, carbonate was an insignificant contributor to the total inorganic anion balance at the tabulated sites, with the majority being made up by bicarbonate (38-90%) and sulphate (7-38%). Absolute bicarbonate concentrations in the study ponds were higher than reported data for most other Shield lakes (Table 51) but were slightly less than in Lake Winnipeg. This was due largely to the anomalously high ionic strength of Spruce Pond water. Overall sulphate levels were slightly higher in the study ponds than in other Shield lakes but were considerably less than in Lake Winnipeg. Sulphate made up a large proportion of total inorganic anions in four of the six study ponds (Spruce, Raspberry, Pine and Birch).

Levels of silica, total dissolved phosphorus (TDP), total dissolved nitrogen (TDN) and total iron were generally higher in the study ponds than in lake and pond water from other sites (Table 51) although they were most similar to data from Nopiming lakes (Hagenson & O'Connor 1978a). Inorganic phosphorus levels were low (<0.02 mg/L) at all sites while nitrate/nitrite levels from the study ponds agreed most closely to those of ELA lakes (ca. 0.01 mg/L) and were lower than many other Shield lakes and rivers. The data of Pip (1985) show, however, that spatial varability in nitrate/nitrite levels of lotic and lentic waters on the southeastern Shield is high (0-3.68 mg/L) and probably relates to the relative amount of terrestrial inputs (particularly river flow).

Dystrophy is a common feature of small lakes on the Precambrian Shield (eg. Hagenson & O'Connor 1978a,b; Armstrong & Schindler 1971) which receive drainage from peatlands. The DOC content of the Pine Falls ponds (9.4-75.1 mg/L) were higher than levels normally encountered in natural waters (0.1-10 mg/L - Stumm & Morgan 1983; ca. 5 mg/L in Lake Alinen Mustajarvi, Finland - Arvola 1984; 4-9 mg/L in Lawrence Lake, USA - Wetzel et al. 1972). DOC levels in ELA lakes range from 0.4 to 21.3 mg/L (Prokopowich 1979). DOC levels in all study ponds except Raspberry were within ranges of total organic carbon (TOC) reported for some Whiteshell and Nopiming lakes (8.5-26.5 mg/L - Hagenson & O'Connor 1978b; 10.0-22.0 mg/L - Hagenson & O'Connor 1978a; 13.9-2.0 mg/L - Brown unpubl.data) although TOC necessarily overestimates DOC by the amount of particulate organic carbon (POC) in an unfiltered sample.

Comparisons of pond dystrophy based on color measurements showed that observed true color (Table 5) for Spruce, Golden and Hike Ponds lay within other reported ranges for Shield lakes (Hagenson & O'Connor 1978a,b) although estimated values for Raspberry, Pine and Birch Ponds (Table 50) were higher.

In addition to the relative paucity of sediment sample collections from lakes on the Precambrian Shield, comparisons of the study ponds with other Shield lakes are further confounded by

the dependence of sediment chemical characterization on analytical protocol and specifically the procedures used to remove the component of interest from the surrounding matrix. To our knowledge, there are no published data detailing sediment chemistry for southern Manitoba Shield lakes. Most available data derive from lakes in the ELA, where major ions of ashed sediments have been measured as total concentrations rather than "exchangeable" values as reported in this study. As Brunskill et al. (1971) report, the discrepancy between total ions and extractable ions in surficial sediments from ELA lakes varied from 10% to near 100% depending on the particular ion. Analyses of interstitial water chemistry based on squeezed core samples also do not provide comparable data because chemical extraction procedures probably remove more ions from a sample than can be recovered through mechanical processes.

Brunskill et al. (1971) report, however, that ELA lake sediments typically contain 20% organic matter (maximum 34%), which is significantly higher than found in most sediments samples collected from the study ponds. This is probably a feature of the relative youth of the study ponds and could also underscore their artificial origins. Conversely, Pip (1985) found that many lakes and ponds on the southeastern Shield have bedrock bottoms with thin surficial layers of sediment, debris, gravel, sand and clay. Relatively few (7% of 100 sites surveyed) had organic substrates.

In general, it is concluded that the Pine Falls ponds were most similar chemically to lakes in the Nopiming and Whiteshell areas. They were significantly more concentrated than the ELA lakes, which are among the most dilute Precambrian Shield lakes (Armstrong & Schindler 1971). At the same time, the study ponds were generally lower in most ions than Lake Winnipeg despite their high conductivity. These data confirm the observation of Hagenson & O'Connor (1978a) that waters in the area east of Lake Winnipeg tend to be more chemically concentrated than those farther onto the Precambrian Shield. Of particular significance were the predominance of Ca/Mg and HCO_3 in the ion balance of the present study ponds. This may be due to the proximity of the westernmost boundary of the Precambrian Shield, the intrusion of calcareous bedrock or glacial drift, or atmospheric deposition of calcareous dust from the bordering prairies.

4.8 Conclusions

The present dataset is one of the most comprehensive for any water body on the Precambrian Shield lake in Manitoba. Since the Shield makes up a major portion of the land area of northern and eastern Manitoba, these results form are an important baseline to further study and identification of water chemical changes arising from herbicide treatment of selected ponds. The data also show that investigations using natural or semi-natural ponds to assess the impact of exogenous manipulations must quantify potential baseline differences carefully. Despite their close geographic situation and circumstances which upon casual inspection

appeared to promote uniformity, the present ponds represent a wide chemical and physical range. Due to their small size, any seemingly trivial inputs and outputs may have profound effects on the constituent environment and hence on potential biological productivity.

4.9 Recommendations for Further Study

Since the sampling program carried out in 1985 was intended to be extensive rather than intensive, several deficiencies can be identified which, for the sake of a complete characterization of pond chemistry and ultimately potential biological productivity, could be addressed in further studies. They are tabulated below in order of decreasing priority and relevance to the planned manipulative study. This list is not exhaustive and suggestions for additions to the present database are welcome.

1. Measurements of dissolved inorganic carbon (DIC) should be made to determine the degree of overestimation of available carbon supply to photosynthetic organisms through the use of titratable alkalinity. The magnitude of this effect would be greatest in the most dystrophic ponds, where weak organic acids may contribute significantly to alkalinity.

2. Water samples should be collected at regular intervals from three or more sites in each pond and at depth to assess the validity of the assumption that the pond waters are chemically homogenous. Measurement of temperature profiles may be used to determine if temporary thermal stratification, which may bear on water circulation, occurs during calm, sunny periods.

3. Extend the analytical ranges of such parameters of true color, potassium, chloride and nitrate/nitrite, whose values normally lay beyond reported limits in certain water samples.

4. Analyses of dissolved organic carbon should be carried out regularly throughout the season so as to assess seasonal patterns, which may be related to allochthanous input of humic materials.

5. Examine in greater detail the relationship between pondwater dissolved organic carbon content and several other chemical constituents of the water column to assess the distinction between total concentrations reported here and biologically available pools.

6. Expand the water chemistry database to include analyses of turbidity and dissolved oxygen concentration. Through effects on relative light diffusion in the water column and availability of chemical species respectively, these parameters (particularly oxygen) may be related to primary production in the ponds.

7. Quantify seasonal patterns of light penetration into the ponds through measurements of direct photometric profiles.

8. Conduct mineralogical analyses of samples of pond sediments and adjacent soil and till to ascertain the nature of the pond watersheds and the potential for chemical interactions with the water columns. This might also include groundwater monitoring to determine the extent of influence of groundwater fluctuations in pond level and topographic surveys to determine effective watershed area. To develop hydrologic budgets of the study ponds, estimates of evapotranspiration would also be necessary.

Recommendations are not offered regarding any change in frequency of water sample collection. The information gained from the collection of data on a weekly basis before and after the heavy rainfall in mid-August supports continuation of the present schedule.

5.0 References

American Public Health Association (APHA) 1980. Standard methods for the examination of water and wastewater, 15th edition. New York, N.Y. 1134p.

Armstrong,F.A.J. & D.W.Schindler. 1971. Preliminary chemical characterization of waters in the Experimental Lakes Area, northwestern Ontario. J.Fish.Res.Bd Can. 28:171-187.

Arvola,L. 1984. Vertical distribution of primary production and phytoplankton in two small lakes with different humus concentration in southern Finland. Hol.Ecol. 7:390-398.

Broch,E.S. & W.Yake. 1969. A modification of Maucha's ionic diagram to include ionic concentrations. Limnol.Oceanogr. 14:933-935.

Brunskill,G.J., D.Povoledo, B.W.Graham & M.P.Stainton. 1971. Chemistry of surface sediments of sixteen lakes in the Experimental Lakes Area, northwestern Ontario. J.Fish.Res.Bd Can. 28:277-294.

Brunskill,G.J., P.Campbell & S.E.M.Elliott. 1979. Temperature, oxygen, conductance and dissolved major elements in Lake Winnipeg. Can.Fish.Mar.Serv.MS Report 1526: v+127p.

Canada Soil Survey Committee (C.S.S.C.). Subcommittee on soil classification. 1977. The Canadian System of Soil Classification. Canadian Dept. Agriculture Publ. 1646. Ottawa, Supply & Services Canada, 164p.

Eloranta,E. 1978. Light penetration in different types of lakes in central Finland. Hol.Ecol. 1:362-366.

Environment Canada. 1978. Water quality data: Manitoba 1961-1976.

----------. 1980. Detailed surface water quality data: Manitoba 1974-1976. 367p.

----------. 1982. Detailed surface water quality data: Manitoba 1977-1979. 253p.

----------. 1984. Detailed surface water quality data: Manitoba 1980-1981. 136p.

Gauch,H.G. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press, England.

Goldsborough,L.G. & D.J.Brown. 1986. Effects of aerial spraying of forestry herbicides on aquatic ecosystems. I. Procedures Manual for project #603. Manitoba Dept. Environment and Workplace Safety and Health, Report 86-6, 29p.

Golterman,H.L. 1969. Methods for Chemical Analysis of Fresh Waters, IBP Handbook No.8. London, Oxford Scientific Publications, 172p.

Hagenson,I. & J.F.O'Connor. 1978a. A fisheries survey of fourteen lakes in Nopiming Provincial Park, 1976. Manitoba Dept. Mines, Natural Resources and Environment, MS Report 78-82, 190p.

Hagenson,I. & J.F.O'Connor. 1978b. A fisheries inventory and lake classification: Whiteshell Provincial Park, 1978. Manitoba Dept. Mines, Natural Resources and Environment, MS Report 78-83, 113p.

Jackson,T.A. & R.E.Hecky. 1980. Depression of primary productivity by humic matter in lake and reservoir waters of the boreal forest zone. Can.J.Fish.Aquat.Sci. 37:2300-2317.

Kilmer,V.J. & L.T.Alexander. 1949. Methods of making mechanical analysis of soils. Soil Sci. 68:15-24.

McFarlane,G.A., W.G.Franzin & A.Lutz. 1979. Chemical analyses of Flin Flon area lake waters and precipitation: 1973-1977. Can. Fish.Mar.Serv.MS Report 1486:v+42p.

Orlóci,L. & N.C.Kenkel. 1984. Introduction to Data Analysis with Applications from Population and Community Ecology. International Co-operative, Fairland, Maryland, USA.

Pip,E. 1985. The ecology of freshwater gastropods on the southwestern edge of the Precambrian Shield. Can.Field Nat. 99:76-85.

Prokopowich,J. 1979. Chemical characterization of epilimnion waters in the Experimental Lakes Area, northwestern Ontario. Can.Fish.Mar.Serv.Tech.Rep. 873: iv+41p.

Richards,L.A. 1954. Diagnosis and improvement of saline and alkali soils. U.S.Dept.Agric., Agric.Handbook No. 670.

Shapiro,J. 1964. Effect of yellow organic acids on iron and other metals in water. J.Am.Wat.Works Assoc. 56:1062-1082.

Shapiro,J. 1966. The relation of humic color to iron in natural waters. Verh.Internat.Verein.Limnol. 16:477-484.

Sorba,E.A., D.Fox & P.Douville. 1980. Analytical Methods: Technical Services Laboratory, 2nd edition. Manitoba Dept. Mines, Natural Resources and Environment.

Stainton,M.P., M.J.Capel & F.A.J.Armstrong. 1977. The Chemical Analysis of Fresh Water, 2nd ed. Can.Fish.Mar.Serv.Misc.Spec. Publ. 25:180p.

Stewart,A.J. & R.G.Wetzel. 1981. Dissolved humic materials: photodegradation, sediment effects, and reactivity with phosphate and calcium carbonate precipitation. Arch.Hydrobiol. 92:265-286.

Stumm,W. & J.J.Morgan. 1981. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters. Toronto, Wiley-Interscience Publications, 780p.

Thornthwaite,C.W. 1948. An approach toward a rational classification of climate. Geograph.Rev. 38:55-94.

Traversy,W.J. 1971. Methods for Chemical Analysis of Waters and Wastewaters. Ottawa, Water Quality Division, Inlands Waters Directorate, Canadian Dept. Fisheries & Forestry, 169p.

Weir,T.R. (Ed.) 1960. Economic Atlas of Manitoba. Man.Dept. Industry and Commerce. Winnipeg.

Wetzel,R.G., P.H.Rich, M.C.Miller & H.L.Allen. 1972. Metabolism of dissolved and particulate detrital carbon in a temperate hard-water lake. Mem.Ist.Ital.Idrobiol.Suppl. 29:185-243.

Wetzel,R.G. 1983. Limnology. Toronto, Saunders College Publishing, 767p.

Appendix A: Relative cloud cover (0-10 where 0 represents complete overcast) at the time of water collection from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	0	3	3	9	9	3
23 May	02	10	10	10	10	10	10
11 June	03	8	8	7	7	7	7
18 June	04	9	7	5	5	5	4
24 June	05	9	5	0	0	0	0
02 July	06	8	7	9	10	10	9
10 July	07	6	6	6	6	7	8
16 July	08	9	7	8	6	3	4
23 July	09	0	0	2	0	0	0
29 July	10	7	5	5	8	9	9
05 August	11	3	2	7	7	7	7
12 August	12	0	0	0	0	0	0
19 August	13	8	8	5	3	3	2
26 August	14	0	3	2	3	2	3
02 Sept.	16	0	0	0	0	0	0
09 Sept.	17	3	0	1	0	2	9
16 Sept.	18	0	0	0	1	3	3
24 Sept.	19	0	0	0	0	0	0
30 Sept.	20	8	8	7	1	0	1
08 Oct.	21	0	0	0	0	0	0
15 Oct.	22	0	0	0	0	0	0
21 Oct.	23	10	10	10	10	10	10
28 Oct.	24	10	9	9	10	10	10
12 Dec.	26						

Appendix B: Pondwater depth (cm) indicated on temporary markers (mean of three markers). Positive numbers represent distances below the initial water recorded on the marker; negative number represent levels above the mark. Depth to sediment/water interface can be calculated by substracting each reading from the initial water depth (bottom). - no data

Date (1985)	Pond					
	Spruce	Raspberry	Pine	Golden	Hike	Birch
23 May	0.0	0.0	0.0	0.0	0.0	0.0
18 June	-	1.5	6.9	8.4	6.5	12.0
24 June	9.0	2.9	10.4	11.8	9.0	16.3
2 July	8.0	1.4	8.4	9.8	7.0	16.7
10 July	11.0	4.7	16.2	18.1	12.4	22.6
16 July	12.9	7.3	23.9	26.0	14.8	28.1
23 July	16.0	11.5	33.5	34.7	18.8	33.7
29 July	18.7	15.8	42.9	43.3	23.5	39.4
31 July	-	-	45.4	46.3	-	-
1 August	-	-	-	-	24.2	41.5
5 August	19.0	17.4	50.6	50.9	26.5	43.0
12 August	19.9	19.1	57.5	57.3	27.0	46.9
19 August	7.1	0.0	16.3	24.9	7.8	25.5
20 August	6.9	-0.8	-	-	-	-
21 August	-	-	14.9	24.0	-	-
22 August	-	-	-	-	7.0	23.8
26 August	8.0	1.5	12.6	22.1	6.5	21.5
2 Sept.	9.9	4.5	14.5	23.5	9.4	24.8
9 Sept.	9.8	2.1	11.8	20.5	9.8	25.4
10 Sept.	9.8	2.1	-	-	-	-
11 Sept.	-	-	12.1	20.9	-	-
12 Sept.	-	-	-	-	11.5	27.4
16 Sept.	11.2	3.1	13.4	20.9	12.2	28.1
24 Sept.	10.9	1.1	11.7	18.1	11.5	28.4
30 Sept.	10.7	0.8	10.5	15.6	11.2	29.2
1 Oct.	10.9	0.8	-	-	-	-
2 Oct.	-	-	10.3	15.3	-	-
3 Oct.	-	-	-	-	11.0	29.1
8 Oct.	10.7	-0.4	9.5	12.7	10.0	28.1
15 Oct.	8.9	-0.7	4.6	8.0	6.0	26.5
21 Oct.	9.2	-	4.7	6.9	5.0	24.6
22 Oct.	9.2	-	-	-	-	-
23 Oct.	-	-	4.1	6.1	-	-
24 Oct.	-	-	-	-	4.5	24.0
28 Oct.	8.7	-	5.2	6.6	-	23.8
12 Dec.	-	-	-	-	-	-
Initial depth (cm)	114	113	114	111	113	113

Appendix C: Distances (m) between stakes positioned around Spruce Pond (1985) eg. A B = distance A to B

A	B	10.0	G	H	10.0	K	X	47.5	P	T	36.9
A	D	27.6	G	DD	46.2	L	M	10.0	P	S	26.9
A	E	35.6	G	CC	47.6	L	Y	48.7	Q	R	10.0
A	F	44.8	G	BB	43.8	L	X	46.4	Q	T	29.9
A	EE	12.0	H	I	10.0	L	W	47.5	Q	S	19.8
B	C	10.0	H	CC	48.4	M	N	10.0	R	S	10.0
B	F	37.3	H	BB	43.6	M	X	45.8	S	T	10.0
C	D	10.0	H	AA	45.2	M	W	44.7	T	U	10.0
C	F	29.7	I	J	10.0	M	V	40.1	U	V	10.0
C	E	19.8	I	BB	45.0	N	W	44.6	V	W	10.0
D	E	10.0	I	AA	44.2	N	V	37.8	W	X	10.0
D	EE	34.7	I	Z	47.8	N	U	46.4	X	Y	10.0
E	F	10.0	J	K	10.0	O	P	10.0	Y	Z	10.0
E	DD	38.3	J	AA	46.5	O	V	34.6	Z	AA	10.0
E	EE	40.5	J	Z	48.1	O	U	41.9	AA	BB	10.0
F	G	10.0	J	Y	49.1	O	T	41.8	BB	CC	10.0
F	EE	48.4	K	L	10.0	P	Q	10.0	CC	DD	10.0
F	DD	44.5	K	Z	48.8	P	R	17.7	DD	EE	10.0
F	CC	45.1	K	Y	47.7	P	U	39.2			

Appendix D: Distances (m) between stakes positioned around Raspberry Pond (1985) eg. A V = distance A to V

A	B	10.0	E	U	29.1	L	N	21.8	Q	G	37.5
A	T	24.9	F	G	10.0	L	O	23.5	Q	I	45.4
A	U	15.6	F	S	31.5	M	O	20.4	Q	H	39.8
A	V	8.0	F	R	34.2	N	M	14.4	Q	L	39.0
A	W	10.2	F	T	27.9	N	O	10.0	Q	R	10.0
A	A'	8.8	F	U	36.7	O	K	29.9	Q	T	27.5
B	C	10.0	G	H	10.0	O	L	23.5	R	D	33.8
B	T	19.7	G	S	37.1	O	P	10.0	R	E	32.9
B	V	12.8	G	R	37.3	P	D	49.5	R	F	34.2
B	U	13.3	G	Q	37.5	P	E	45.1	R	G	37.3
C	D	10.0	G	T	35.4	P	F	41.9	R	H	41.9
C	S	25.6	H	I	10.0	P	G	39.8	R	I	49.1
C	U	16.0	H	Q	39.8	P	H	39.7	R	J	50.5
C	T	16.7	H	S	43.7	P	I	43.2	R	T	18.3
C	V	20.7	I	J	10.0	P	J	40.7	S	T	8.9
D	E	10.0	I	Q	45.4	P	Q	10.0	T	P	37.1
D	S	25.9	I	P	43.2	Q	J	45.1	T	U	10.0
D	T	17.9	J	K	10.0	Q	K	41.6	U	V	10.0
D	U	22.2	J	P	40.7	P	K	35.4	V	W	11.5
D	V	29.3	J	O	37.1	P	L	31.1	V	A'	11.7
E	F	10.0	K	L	10.0	Q	D	41.2	W	A'	2.7
E	S	27.5	K	N	30.0	Q	E	38.4			
E	T	21.7	K	O	29.9	Q	F	37.1			

Appendix E: Distances (m) between stakes positioned around Pine Pond (1985) eg. A B = distance A to B

A	B	10.0	H	I	10.0	U	Q	24.6	Y	L	22.4
A	I	6.9	I	J	10.0	U	S	18.5	Y	M	25.2
A	J	15.4	J	K	13.5	U	Q	24.6	Y	L	22.4
A	I	6.9	I	J	10.0	U	S	18.5	Y	M	25.2
A	J	15.4	J	K	13.5	U	V	11.5	Y	Z	10.0
B	C	10.0	K	L	10.0	V	P	30.4	Z	K	14.7
B	H	6.6	L	M	9.4	V	Q	28.8	Z	L	20.4
B	I	13.5	M	N	8.2	V	W	10.0	Z	AA	10.0
C	D	10.0	M	O	13.4	W	O	28.5	AA	K	12.4
C	G	6.3	N	O	11.2	W	P	29.0	AA	L	21.9
C	H	13.0	O	P	10.0	W	X	10.0	AA	BB	10.0
D	E	12.3	P	Q	10.0	W	X	9.5	BB	A	10.0
D	F	7.4	Q	R	8.7	X	L	24.8	B	J	8.7
D	G	11.3	Q	S	9.3	X	M	23.7	BB	K	19.2
E	F	10.8	R	S	6.0	X	N	31.6			
F	G	10.0	S	T	10.0	X	O	29.9			
G	H	10.5	T	U	10.0	X	Y	10.0			

Appendix F: Distances (m) between stakes positioned around Golden Pond (1985) eg. A B = distance A to B

A	B	5.0	G	B'	16.9	D'	S'	13.4	M'	N'	7.0
A	K	6.6	G	C'	12.4	D'	T'	20.5	N'	O'	10.0
B	C	10.0	G	DD'	28.1	E'	F'	10.0	O'	H'	15.5
B	I	14.9	H	I	5.4	E'	S'	18.5	O'	P'	11.0
B	J	8.8	I	J	10.0	E'	R'	17.1	P'	Q'	10.0
B	K	7.4	J	K	10.8	F'	G'	10.0	Q'	R'	10.0
C	D	10.0	J	F'	14.5	F'	Q'	20.4	R'	S'	10.0
C	J	13.7	A'	B'	7.3	F'	R'	21.3	S'	T'	10.0
C	I	12.4	A'	X'	29.6	G'	H'	10.0	T'	U'	10.0
C	H	16.0	A'	Y'	28.9	G'	P'	19.0	U'	V'	10.0
D	E	10.0	A'	Z'	28.8	G'	Q'	21.9	V'	W'	10.0
D	J	20.0	A'	BB'	34.3	H'	I'	8.3	W'	X'	10.0
D	I	13.4	A'	CC'	30.4	H'	P'	13.8	X'	Y'	10.0
D	H	13.8	A'	DD'	26.3	H'	Q'	20.9	Y'	Z'	7.4
E	F	8.0	B'	V'	16.5	I'	J'	10.0	Z'	AA'	9.4
E	J	26.1	B'	Y'	22.4	I'	N'	14.2	Z'	BB'	8.0
E	I	16.9	B'	Z'	23.1	I'	O'	11.8	AA'	BB'	10.0
E	H	13.7	B'	C'	10.0	I'	P'	16.3	BB'	CC'	10.0
E	FF'	8.2	B'	U'	21.6	J'	K'	9.0	CC'	Z'	13.8
F	G	2.7	B'	W'	22.1	J'	L'	17.0	CC'	DD'	10.0
F	H	11.1	B'	X'	22.6	J'	M'	15.3	DD'	Z'	21.2
F	A'	9.9	C'	D'	10.0	J'	N'	20.6	DD'	EE'	9.0
F	Z'	34.9	C'	T'	20.0	J'	O'	21.4	EE'	Z'	26.4
F	DD'	25.9	C'	U'	19.3	K'	M'	15.6	EE'	FF'	10.0
F	EE'	17.7	C'	V'	19.5	L'	I'	20.9	FF'	F	8.9
G	H	10.0	C'	W'	27.6	L'	M'	12.7	FF'	Z'	27.2
G	A'	10.0	D'	E'	10.0	M'	I'	12.4			

Appendix G: Distances (m) between stakes positioned around Hike Pond (1985) eg. A B = distance A to B

A	B	10.0	R	E	21.4	CC	DD	10.0	NN	Z	46.6
B	C	10.0	R	F	16.0	DD	EE	10.0	NN	OO	9.8
C	D	10.0	R	G	19.3	EE	FF	6.3	NN	PP	12.4
D	E	17.5	R	S	10.0	FF	GG	10.0	OO	PP	13.7
E	F	10.0	S	E	18.4	GG	HH	10.0	PP	QQ	10.0
F	G	11.7	S	T	14.0	HH	EE	23.5	QQ	RR	10.0
G	H	13.5	T	D	27.4	HH	FF	21.0	RR	SS	10.0
H	I	10.0	T	E	23.3	HH	II	10.0	SS	TT	13.6
I	J	9.4	T	U	10.0	II	EE	29.8	TT	UU	12.9
J	K	10.0	U	C	32.7	II	JJ	10.0	UU	TT	13.0
K	L	10.0	U	D	29.1	JJ	DD	34.2	UU	VV	7.6
L	M	3.7	U	V	10.0	JJ	EE	35.5	VV	RR	18.1
M	K	10.8	V	B	37.7	JJ	KK	11.2	VV	SS	13.9
M	N	10.0	V	C	34.7	KK	CC	39.3	VV	TT	12.4
N	J	11.3	V	W	10.0	KK	DD	39.7	VV	WW	9.8
N	K	9.2	W	A	44.6	KK	LL	6.4	WW	PP	21.9
N	O	10.0	W	B	40.6	LL	AA	41.7	WW	QQ	15.5
O	H	18.3	W	X	10.0	LL	BB	37.8	WW	RR	13.4
O	I	14.8	X	A	43.3	LL	CC	34.6	WW	XX	10.0
O	J	6.6	X	Y	13.0	LL	MM	13.0	XX	A	11.8
O	P	10.0	Y	A	43.6	MM	A	33.0	XX	NN	29.3
P	G	20.6	Y	Z	10.0	MM	Z	40.8	XX	OO	33.7
P	H	15.6	Z	A	47.6	MM	AA	40.0	XX	PP	20.3
P	Q	10.0	Z	AA	10.0	MM	NN	10.0			
Q	G	16.8	AA	BB	10.7	NN	A	26.6			
Q	R	10.0	BB	CC	10.0	NN	Y	47.9			

Appendix H: Distances (m) between stakes positioned around Birch Pond (1985) eg. A B = distance A to B

A	B	10.0	L	M	10.0	BB	DDD	44.1	OO	CCC	26.6
A	CCC	37.1	M	N	10.0	CC	DD	9.0	OO	DDD	34.5
B	C	10.0	N	O	10.0	CC	DDD	43.3	PP	QQ	8.6
B	CCC	33.8	O	P	10.0	DD	EE	11.0	QQ	RR	3.8
C	D	10.0	P	Q	10.0	EE	FF	13.0	QQ	CCC	22.5
C	CCC	34.1	Q	R	12.2	FF	GG	10.0	RR	BBB	20.1
D	E	10.0	R	S	10.0	GG	HH	10.0	RR	SS	10.0
D	CCC	38.4	R	DDD	28.2	HH	II	10.0	RR	VV	18.0
E	F	10.0	S	T	7.4	II	JJ	12.0	RR	WW	23.1
E	CCC	38.5	S	DDD	27.3	JJ	FF	26.0	RR	CCC	25.0
F	G	10.0	T	Y	9.6	JJ	GG	27.2	SS	TT	9.0
F	CCC	30.8	T	Z	15.8	JJ	HH	19.2	SS	UU	12.3
G	H	8.0	T	AA	21.1	JJ	KK	10.0	SS	VV	11.3
G	CCC	25.4	T	BB	25.5	JJ	LL	17.4	TT	UU	8.5
H	I	10.0	T	U	10.0	KK	LL	10.0	UU	VV	8.4
H	Q	37.4	T	DDD	29.0	LL	FF	36.1	VV	WW	5.3
H	R	41.7	U	V	10.0	LL	MM	10.0	WW	XX	10.0
H	CCC	21.0	U	W	18.6	MM	EE	38.0	WW	ZZ	12.6
H	DDD	24.0	U	X	9.8	MM	FF	37.7	WW	AAA	10.3
I	J	10.0	U	Y	7.0	MM	NN	10.0	WW	BBB	9.9
I	P	34.3	V	W	12.0	NN	DD	39.2	XX	YY	10.0
I	Q	35.2	W	X	10.0	NN	EE	41.6	XX	ZZ	8.4
J	K	10.0	X	Y	10.0	NN	OO	6.0	YY	ZZ	11.0
J	N	25.5	Y	Z	10.0	OO	BB	50.1	ZZ	AAA	10.0
J	O	32.1	Z	AA	10.0	OO	CC	42.9	AAA	BBB	15.0
J	P	36.0	Z	DDD	44.0	OO	DD	41.2	BBB	A	14.3
K	L	10.0	AA	BB	10.0	OO	PP	10.0	BBB	CCC	38.1
K	M	17.5	AA	DDD	45.4	OO	QQ	12.8	CCC	DDD	18.8
K	N	25.7	BB	CC	10.0	OO	TT	52.6			

Appendix I: Estimated areas of Spruce Pond isobaths (9 July, 1985)

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
0	5167.7	5167.7
0.2	4698.8	4698.8
0.4	4307.9	
	(9.3)	4298.6
0.6	3981.2	3981.2
0.8	3610.9	3610.9
1.0	3244.3	
	58.3	3302.6
1.2	2933.6	2933.6
1.4	2669.3	2669.3
1.6	2453.9	2453.9
1.8	2146.9	2146.9
2.0	1731.3	1731.3
2.2	1399.8	1399.8
2.4	975.1	975.1
2.6	469.2	
	9.9	479.1
2.8	52.0	52.0

Appendix J: Estimated areas of Raspberry Pond isobaths (26 June, 1985)

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
0	2597.3	2597.3
0.2	2371.9	2371.9
0.4	2155.5	
	(4.2)	2151.3
0.6	1916.8	1916.8
0.8	1616.5	
	(14.7)	
	(7.7)	
	(7.4)	1586.7
1.0	757.8	
	574.6	1332.4
1.2	443.5	
	295.6	
	244.0	983.1
1.4	297.7	
	204.6	
	58.8	
	29.0	590.1
1.6	123.5	
	112.9	236.4
1.8	45.9	
	2.9	48.8

Appendix K: Estimated areas of Pine Pond isobaths (25 July, 1985)

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
0	1994.9	
	(15.1)	1979.8
0.2	1664.1	1664.1
0.4	1264.7	
	147.4	1412.1
0.6	1094.5	
	52.3	
	5.6	1152.4
0.8	867.6	
	35.4	
	6.3	909.3
1.0	750.8	
	22.6	
	0.8	774.2
1.2	650.3	
	10.1	660.4
1.4	573.9	
	(0.9)	573.0
1.6	492.7	
	(12.5)	
	(0.9)	479.3
1.8	369.0	
	(3.6)	365.4
2.0	228.7	228.7
2.2	107.9	107.9
2.4	43.5	43.5
2.6	15.2	15.2
2.8	3.9	3.9

Appendix L: Estimated areas of Golden Pond isobaths (22 July, 1985). Asterisks represent area at high water line.

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
0	313.1 (391.1*)	
	2502.9	
	52.3*	
	(154.1)	
	(3.1)	2658.8 (2946.3*)
0.2	226.6	
	2079.3	
	(13.7)	2292.2
0.4	176.0	
	1848.1	
	(34.6)	1989.5
0.6	1552.5	
	146.9	1699.4
0.8	1296.5	
	121.5	
	22.3	1440.3
1.0	1015.5	
	77.6	
	11.7	
	11.7	1116.5
1.2	814.3	
	41.1	855.4
1.4	594.6	
	21.3	
	4.7	620.6
1.6	476.4	
	9.1	485.5
1.8	277.7	
	52.2	329.9
2.0	167.4	167.4
2.2	97.7	97.7
2.4	72.5	72.5
2.6	48.4	48.4
2.8	22.9	22.9
3.0	2.9	2.9

Appendix M: Estimated areas of Hike Pond isobaths (7 August, 1985)

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
0	6325.3	6325.3
0.2	5626.9	
	4.5	
	(4.6)	
	(3.2)	
	(2.4)	5621.2
0.4	5086.2	
	(19.5)	
	(7.9)	5058.8
0.6	4559.0	
	14.2	
	(26.9)	
	(4.0)	4542.3
0.8	4102.2	
	(50.3)	4051.9
1.0	3708.3	
	(77.6)	3630.7
1.2	2713.5	
	647.0	
	(143.9)	3216.6
1.4	2185.1	
	563.8	2748.9
1.6	1770.8	
	464.1	
	(4.1)	2230.8
1.8	1225.1	
	392.9	
	108.3	
	15.7	1742.0
2.0	1028.7	
	316.7	
	83.2	1428.6
2.2	775.9	
	235.7	
	57.0	
	37.5	
	11.7	1117.8
2.4	662.7	
	133.2	
	28.7	
	12.5	837.1
2.6	584.8	
	100.4	
	10.2	695.4
2.8	477.4	
	81.0	558.4

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
3.0	416.3	
	52.5	468.8
3.2	334.3	
	9.3	343.6
3.4	215.1	215.1
3.6	139.9	139.9
3.8	107.5	107.5
4.0	50.5	50.5

Appendix N: Estimated areas of Birch Pond isobaths (8 August, 1985)

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
0	7471.6	
	209.6	
	(340.5)	
	(140.1)	
	(26.7)	
	(24.6)	
	(22.4)	
	(15.9)	
	(8.9)	7102.1 (7681.2*)
0.2	6537.5	
	82.5	
	(51.4)	
	(50.2)	
	(27.6)	6490.8
0.4	6059.3	
	74.3	
	48.4	
	12.3	
	(75.2)	
	(69.6)	
	(36.7)	6012.8
0.6	5764.9	
	30.6	
	5.7	
	(98.4)	
	(79.7)	
	(46.7)	
	(7.7)	
	(2.7)	5566.0
0.8	5147.1	
	6.7	
	(92.3)	
	(69.2)	
	(4.7)	
	(3.7)	
	(2.6)	4981.3
1.0	4351.6	
	(109.7)	
	(94.1)	4147.8
1.2	3486.7	
	11.3	
	8.6	
	1.4	
	(122.7)	3385.3
1.4	3229.7	
	(149.9)	
	(2.7)	3077.1

Depth (m)	Individual Area (m^2)	Isobath Area (m^2)
1.6	2712.2	
	(11.5)	2700.7
1.8	2222.5	
	115.3	2337.8
2.0	1956.7	
	105.4	2062.1
2.2	1745.0	
	96.1	
	(4.2)	1836.9
2.4	1172.7	
	195.7	
	85.2	1453.6
2.6	936.6	
	100.0	
	67.5	1104.1
2.8	334.9	
	280.0	
	50.3	
	49.7	
	30.8	745.7
3.0	142.6	
	74.9	
	65.2	
	31.2	
	26.3	
	18.2	
	16.5	374.9
3.2	61.7	
	32.5	
	18.4	
	14.2	
	1.3	128.1
3.4	18.0	
	4.8	
	1.5	
	1.5	25.8
3.6	10.0	10.0

Appendix O: Estimated volume of depth intervals of Spruce Pond (9 July, 1985)

Top Depth (m)	Area (m^2)	Bottom Depth (m)	Area (m^2)	Volume (m^3)
0	5167.7	0.2	4698.8	986.3
0.2	4698.8	0.4	4298.6	899.4
0.4	4298.6	0.6	3981.2	827.8
0.6	3981.2	0.8	3610.9	758.9
0.8	3610.9	1.0	3302.6	691.1
1.0	3302.6	1.2	2933.6	623.3
1.2	2933.6	1.4	2669.3	560.1
1.4	2669.3	1.6	2453.9	512.2
1.6	2453.9	1.8	2146.9	459.7
1.8	2146.9	2.0	1731.3	387.1
2.0	1731.3	2.2	1399.8	312.5
2.2	1399.8	2.4	975.1	236.2
2.4	975.1	2.6	479.1	142.5
2.6	479.1	2.8	52.0	45.9
2.8	52.0	2.9	0	1.7
Total Volume (m^3)				7444.7

Appendix P: Estimated volume of depth intervals of Raspberry Pond (26 June, 1985)

Top Depth (m)	Area (m^2)	Bottom Depth (m)	Area (m^2)	Volume (m^3)
0	2597.3	0.2	2371.9	496.7
0.2	2371.9	0.4	2151.3	452.1
0.4	2151.3	0.6	1916.8	406.5
0.6	1916.8	0.8	1586.7	349.8
0.8	1586.7	1.0	1332.4	291.5
1.0	1332.4	1.2	983.1	230.6
1.2	983.1	1.4	590.1	155.6
1.4	590.1	1.6	236.4	79.9
1.6	236.4	1.8	48.8	26.1
1.8	48.8	1.95	0	2.4
Total Volume (m^3)				2491.2

Appendix Q: Estimated volume of depth intervals of Pine Pond (25 July, 1985)

Top Depth (m)	Area (m^2)	Bottom Depth (m)	Area (m^2)	Volume (m^3)
0	1979.8	0.2	1664.1	363.9
0.2	1664.1	0.4	1412.1	307.3
0.4	1412.1	0.6	1152.4	256.0
0.6	1152.4	0.8	909.3	205.7
0.8	909.3	1.0	774.2	168.2
1.0	774.2	1.2	660.4	143.3
1.2	660.4	1.4	573.0	123.2
1.4	573.0	1.6	479.3	105.1
1.6	479.3	1.8	365.4	84.2
1.8	365.4	2.0	228.7	58.9
2.0	228.7	2.2	107.9	32.9
2.2	107.9	2.4	43.5	14.7
2.4	43.5	2.6	15.2	5.6
2.6	15.2	2.8	3.9	1.8
2.8	3.9	2.87	0	0.1
Total Volume (m^3)				1870.9

Appendix R: Estimated volume of depth intervals of Golden Pond (22 July, 1985)

Top Depth (m)	Area (m^2)	Bottom Depth (m)	Area (m^2)	Volume (m^3)
0	2658.8	0.2	2292.2	494.6
0.2	2292.2	0.4	1989.5	427.8
0.4	1989.5	0.6	1699.4	368.5
0.6	1699.4	0.8	1440.3	313.6
0.8	1440.3	1.0	1116.5	255.0
1.0	1116.5	1.2	855.4	196.6
1.2	855.4	1.4	620.6	147.0
1.4	620.6	1.6	485.5	110.3
1.6	485.5	1.8	329.9	81.0
1.8	329.9	2.0	167.4	48.8
2.0	167.4	2.2	97.7	26.2
2.2	97.7	2.4	72.5	17.0
2.4	72.5	2.6	48.4	12.0
2.6	48.4	2.8	22.9	7.0
2.8	22.9	3.0	2.9	2.3
3.0	2.9	3.08	0	0.1
Total Volume (m^3)				2507.8

Appendix S: Estimated volume of depth intervals of Hike Pond (7 August, 1985)

Top Depth (m)	Area (m^2)	Bottom Depth (m)	Area (m^2)	Volume (m^3)
0	6325.3	0.2	5621.2	1194.0
0.2	5621.2	0.4	5058.8	1067.5
0.4	5058.8	0.6	4542.3	959.6
0.6	4542.3	0.8	4051.9	859.0
0.8	4051.9	1.0	3630.7	767.9
1.0	3630.7	1.2	3216.6	684.3
1.2	3216.6	1.4	2748.9	595.9
1.4	2748.9	1.6	2230.8	497.1
1.6	2230.8	1.8	1742.0	396.3
1.8	1742.0	2.0	1428.6	316.5
2.0	1428.6	2.2	1117.8	254.0
2.2	1117.8	2.4	837.1	194.8
2.4	837.1	2.6	695.4	153.0
2.6	695.4	2.8	558.4	125.1
2.8	558.4	3.0	468.8	102.6
3.0	468.8	3.2	343.6	80.9
3.2	343.6	3.4	215.1	55.4
3.4	215.1	3.6	139.9	35.2
3.6	139.9	3.8	107.5	24.7
3.8	107.5	4.0	50.5	15.4
4.0	50.5	4.07	0	1.2
Total Volume (m^3)				8380.4

Appendix T: Estimated volume of depth intervals of Birch Pond (8 August, 1985)

Top Depth (m)	Area (m^2)	Bottom Depth (m)	Area (m^2)	Volume (m^3)
0	7102.1	0.2	6490.8	1358.8
0.2	6490.8	0.4	6012.8	1250.1
0.4	6012.8	0.6	5566	1157.6
0.6	5566	0.8	4981.3	1054.2
0.8	4981.3	1.0	4147.8	911.6
1.0	4147.8	1.2	3385.3	752.0
1.2	3385.3	1.4	3077.1	646.0
1.4	3077.1	1.6	2700.7	577.4
1.6	2700.7	1.8	2337.8	503.4
1.8	2337.8	2.0	2062.1	439.7
2.0	2062.1	2.2	1836.9	389.7
2.2	1836.9	2.4	1453.6	328.3
2.4	1453.6	2.6	1104.1	255.0
2.6	1104.1	2.8	745.7	183.8
2.8	745.7	3.0	374.9	110.0
3.0	374.9	3.2	128.1	48.1
3.2	128.1	3.4	25.8	14.0
3.4	25.8	3.6	10	3.5
3.6	10	3.8	0	0.1
Total Volume (m^3)				9983.3

Appendix U: Proportion (%) of clay (particles < 0.002mm diameter) in total inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	81	93	39	4	31	26
2	85	89	20	19	22	8
3	76	88	11	17	13	22
4	83	88	18	7	10	39
5	87	32	30	4	24	25
6	76	86	20	12	3	23
7	70	69	29	14	22	20
8	80	88	14	16	11	23
9	76	84		18	24	12
10	83			5	14	8
11	79				6	1
12	78				21	21
13						25
Min	70	32	11	4	3	1
Max	87	93	39	19	31	39
Median	80	88	20	13	18	22
Mean	80	80	23	12	17	19
SD	5	19	9	6	8	10

Appendix V: Proportion (%) of silt (particles 0.002-0.05mm diameter) in inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	14	5	36	4	23	42
2	13	8	36	53	24	9
3	17	9	51	35	23	35
4	14	11	38	13	28	49
5	10	32	54	18	37	39
6	17	6	19	50	2	52
7	23	24	46	50	56	33
8	16	9	30	40	28	52
9	19	10		50	35	26
10	13			8	30	25
11	14				12	0
12	17				67	59
13						62
Min	10	5	19	4	2	0
Max	23	32	54	53	67	62
Median	15	9	37	38	28	39
Mean	16	13	39	32	30	37
SD	3	9	11	19	17	19

Appendix W: Proportion (%) of total sand (particles > 0.05mm diameter) in inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	5	2	25	92	46	32
2	2	3	44	28	54	83
3	7	3	38	48	64	43
4	3	1	44	80	62	12
5	3	36	16	78	39	36
6	7	8	61	38	95	25
7	7	7	25	36	22	47
8	4	3	56	44	61	25
9	5	6		32	41	62
10	4			87	56	67
11	7				82	99
12	5				12	20
13						13
Min	2	1	16	28	12	12
Max	7	36	61	92	95	99
Median	5	3	41	46	55	36
Mean	5	8	39	56	53	43
SD	2	11	16	25	23	27

Appendix X: Proportion (%) of very fine sand (particles 0.05-0.10mm diameter) in inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). - not determined. See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	-	-	11	6	4	27
2	-	-	28	23	17	15
3	-	-	29	39	35	35
4	-	-	34	47	49	6
5	-	6	14	38	31	25
6	-	-	23	35	3	20
7	-	-	8	28	20	31
8	-	-	32	13	42	22
9	-	-		27	29	24
10	-			16	39	29
11	-				17	1
12	-				10	15
13						8

Appendix Y: Proportion (%) of fine sand (particles 0.1-0.25mm diameter) in inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). - not determined. See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	-	-	6	18	9	3
2	-	-	12	4	12	34
3	-	-	8	8	26	7
4	-	-	9	31	12	2
5	-	5	2	24	6	6
6	-	-	23	3	4	4
7	-	-	9	7	1	13
8	-	-	16	5	16	3
9	-	-		3	7	19
10	-			29	12	26
11	-				25	1
12	-				3	4
13						2

Appendix Z: Proportion (%) of medium sand (particles 0.25-0.5mm diameter) in inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). - not determined. See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	-	-	4	25	8	2
2	-	-	3	1	8	31
3	-	-	1	1	3	1
4	-	-	1	2	1	2
5	-	7	0	13	1	2
6	-	-	8	0	13	1
7	-	-	7	1	1	3
8	-	-	7	8	2	0
9	-	-		2	2	16
10	-			23	3	9
11	-				23	10
12	-				0	1
13						1

Appendix AA: Proportion (%) of coarse sand (particles 0.5-1.0mm diameter) in organic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). - not determined. See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	-	-	3	22	9	0
2	-	-	1	0	11	3
3	-	-	0	0	0	0
4	-	-	0	0	0	1
5	-	8	0	3	0	2
6	-	-	4	0	37	0
7	-	-	1	0	0	0
8	-	-	1	11	1	0
9	-	-		0	2	3
10	-			13	1	2
11	-				13	50
12	-				0	0
13						1

Appendix BB: Proportion (%) of very coarse sand (particles 1.0-2.0mm diameter) in inorganic residue of surficial sediment samples collected from study ponds (25-26 September, 1985). - not determined. See Figures 18-23 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	-	-	1	21	6	0
2	-	-	0	0	6	9
3	-	-	0	0	0	0
4	-	-	0	0	0	1
5	-	10	0	0	1	1
6	-	-	3	0	38	0
7	-	-	0	0	0	0
8	-	-	0	7	0	0
9	-	-		0	1	0
10	-			6	1	1
11	-				4	37
12	-				0	0
13						1

Appendix CC: Time of collection (Central Daylight Time) of water from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	1400	1540	1120	1055	1010	1240
23 May	02	1200	1430	0950	1145	1400	1850
11 June	03	1255	1130	1500	1530	1445	1400
18 June	04	0955	1040	1145	1230	1255	1320
24 June	05	1115	1155	1310	1340	1410	1440
02 July	06	0950	1030	1115	1135	1200	1220
10 July	07	1155	1220	1300	1320	1420	1445
16 July	08	0955	1025	1100	1125	1150	1210
23 July	09	1155	1225	1300	1330	1355	1415
29 July	10	1530	1600	1635	1655	1722	1745
05 August	11	1445	1515	1550	1615	1640	1700
12 August	12	1750	1601	1601	1620	1635	1500
19 August	13	1220	1315	1400	1420	1440	1500
26 August	14	1330	1400	1505	1525	1550	1625
02 Sept.	16	1042	1138	1229	1259	1338	1453
09 Sept.	17	1256	1405	1548	1619	1712	1819
16 Sept.	18	1031	1118	1252	1331	1412	1511
24 Sept.	19	1143	1244	1415	1458	1554	1650
30 Sept.	20	1209	1243	1340	1408	1509	1539
08 Oct.	21	1036	1102	1219	1246	1315	1409
15 Oct.	22	1023	1059	1350	1505	1206	1141
21 Oct.	23	1339	1420	1516	1546	1613	1644
28 Oct.	24	1142	1238	1330	1408	1444	1515
12 Dec.	26	.	.	.	.	.	.

Appendix DD: Laboratory numbers assigned to water samples collected from study ponds (1985).

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	13255	13260	13262	13263	13257	13264
	01	13254					
23 May	02	14274	14275	14277	14278	14279	14276
11 June	03	15606	15607	15610	15609	15608	15611
18 June	04	16107	16108	16109	16110	16111	16112
24 June	05	16578	16579	16581	16580	16582	16583
02 July	06	17220	17223	17221	17224	17222	17225
10 July	07	17918	17919	17921	17920	17922	17923
16 July	08	18568	18569	18571	18570	18577	18573
23 July	09	19055	19056	19057	19058	19059	19060
29 July	10	19512	19513	19514	19515	19516	19517
05 August	11	19938	19939	19940	19941	19942	19943
12 August	12	20525	20526	20527	20528	20529	20530
19 August	13	21001	21002	21004	21003	21005	21006
26 August	14	21546	21547	21548	21549	21550	21551
02 Sept.	16	21856	21857	21859	21858	21860	21861
09 Sept.	17	22269	22270	22271	22272	22273	22274
16 Sept.	18	22616	22617	22618	22619	22620	22621
24 Sept.	19	23155	23156	23157	23158	23159	23160
30 Sept.	20	23449	23450	23451	23452	23453	23454
08 Oct.	21	24015	24016	24017	24018	24019	24020
15 Oct.	22	24288	24289	24290	24291	24292	24293
21 Oct.	23	24715	24716	24717	24718	24719	24720
28 Oct.	24	25169	25171	25173	25175	25177	25179
28 Oct.	25	25171	25172	25174	25176	25179	25180
12 Dec.	26	27793	27794	27795	27796	27797	27798
	26	27783					

Appendix EE: Ion balance error (%) for water samples collected from study ponds (1985). (. = no data)

Collect Date	Sample Number	Pond					
		Spruce	Raspberry	Pine	Golden	Hike	Birch
13 May	01	2.53	4.89	18.53	.	2.26	.
	01	2.60	.	.	.	.	.
23 May	02	8.70	11.01	2.03	3.94	5.18	14.17
11 June	03	3.89	10.99	6.30	5.31	3.41	17.96
18 June	04	1.32	4.18	8.34	3.75	4.39	13.67
24 June	05	2.91	5.28	10.67	4.86	6.22	14.06
02 July	06	2.85	9.33	14.75	5.09	5.30	19.24
10 July	07	2.57	5.53	6.00	4.21	1.50	14.50
16 July	08	5.55	9.84	10.88	1.00	2.85	17.29
23 July	09	1.80	3.60	10.18	10.38	3.29	15.12
29 July	10	1.11	9.93	11.45	1.44	1.18	4.67
05 August	11	4.78	6.99	18.20	9.15	7.08	11.91
12 August	12	4.77	8.79	8.14	3.42	0.30	1.44
19 August	13	2.38	18.60	13.80	3.86	4.63	12.11
26 August	14	3.03	21.83	2.74	6.40	5.45	1.97
02 Sept.	16	2.02	10.94	5.61	0.61	2.30	5.92
09 Sept.	17	1.50	14.64	13.39	3.55	3.32	13.73
16 Sept.	18	2.83	14.81	13.51	6.46	4.46	17.38
24 Sept.	19	2.69	15.18	11.38	5.17	4.05	15.56
30 Sept.	20	5.05	16.51	16.03	4.51	5.75	13.06
08 Oct.	21	8.10	16.25	20.76	7.39	7.86	14.33
15 Oct.	22	8.28	18.14	16.47	7.99	6.40	16.13
21 Oct.	23	7.49	15.94	10.91	7.00	4.58	19.90
28 Oct.	24	7.83	20.04	14.48	5.33	4.14	11.61
28 Oct.	25	4.52	18.68	13.65	5.47	3.33	10.75
12 Dec.	26	3.23	19.98	7.06	3.67	2.83	11.48
	26	3.76	.	.	.	.	.
Minimum		1.11	3.60	2.03	0.61	0.30	1.44
Maximum		8.70	21.83	20.76	10.38	7.86	19.90
Median		3.03	11.01	11.38	4.98	4.14	13.90
Mean		4.00	12.48	11.41	5.00	4.08	12.83
StdDev(n-1)		2.28	5.58	4.85	2.36	1.85	4.95

Appendix FF: Summary of pondwater chemical and physical characteristics (1985) used in cluster analyses.

Parameter	Spruce	Raspberry	Pine	Golden	Hike	Birch
secchi (m)	2.60*	0.62	1.01	2.46	1.88	1.41
color	16	50*	49*	11	8	50*
conduct.(uS/cm)	474.1	135.1	47.6	88.7	114.1	48.6
pH	8.20	6.84	6.67	7.64	7.78	7.05
tot.alk. (mg/L)	33.4	53.1	20.6	43.5	56.2	22.0
bicarb.alk.(mg/L)	283.4	64.8	25.1	52.9	68.3	26.8
carb.alk.(mg/L)	0.6	0	0	0.1	0.1	0
calcium (mg/L)	30.40	15.00	5.22	11.30	12.20	4.89
magnesium (mg/L)	30.10	9.50	2.62	3.66	5.12	2.62
hardness (mg/L)	199.1	76.5	23.8	43.3	51.4	23.1
manganese (mg/L)	0.03*	0.17	0.14	0.04*	0.07	0.03*
iron (mg/L)	0.04	0.99	1.34	0.19	0.21	2.57
potassium (mg/L)	5.00*	5.00*	5.00*	5.00*	5.00*	5.00*
sodium (mg/L)	37.30	5.84	1.38*	1.33	3.63	1.72
chloride (mg/L)	2.0*	2.2*	2.0*	2.0*	2.0*	2.0*
fluoride (mg/L)	0.26	0.11*	0.10*	0.10*	0.12*	0.10*
sulphate (mg/L)	27.9	17.8	4.0	1.1	1.4	3.3
TKN (mg/L)	1.0	1.8	1.1	0.71	0.62	0.67
ammonia (mg/L)	0.02*	0.03*	0.02*	0.02*	0.02*	0.02*
nitrate (mg/L)	0.01*	0.01*	0.01*	0.01*	0.01*	0.01*
TP (mg/L)	0.024	0.041	0.055	0.035	0.023	0.025
silica (mg/L)	1.6	6.4	2.9	1.3	2.1	2.3
DOC (mg/L)	21.2	67.6	25.1	10.4	10.5	17.9

Appendix GG: Laboratory numbers (Manitoba Provincial Soil Testing Laboratory) assigned to surficial sediment samples collected from study ponds (25-26 September, 1985). See Figures 24-29 for sample locations.

Sample No.	Spruce	Raspberry	Pine	Golden	Hike	Birch
1	3228	3240	3249	3257	3267	3279
2	3229	3241	3250	3258	3268	3280
3	3230	3242	3251	3259	3269	3281
4	3231	3243	3252	3260	3270	3282
5	3232	3244	3253	3261	3271	3283
6	3233	3245	3254	3262	3272	3284
7	3234	3246	3255	3263	3273	3285
8	3235	3247	3256	3264	3274	3286
9	3236	3248		3265	3275	3287
10	3237			3266	3276	3288
11	3238				3277	3289
12	3239				3278	3290
13						3291

Appendix HH: Summary of chemical and physical characteristics (median of spatial samples) of surficial sediment samples from the study ponds (1985) used in cluster analyses.

Parameter	Spruce	Raspberry	Pine	Golden	Hike	Birch
number samples	12	9	8	10	12	13
clay (%)	80	88	20	13	18	22
sand (%)	5	3	41	46	55	36
salinity (mS/cm)	1.9	1.3	0.2	0.2	0.2	0.2
pH	7.7	7.8	5.3	5.9	5.7	5.0
sodium (ppm)	228	190	35	36	42	26
potassium (ppm)	450	405	145	114	154	150
calcium (ppm)	8295	8660	810	880	960	800
magnesium (ppm)	2355	2180	145	115	145	140
iron (ppm)	57	51	74	66	71	80
manganese (ppm)	29.0	33.0	32.5	30.0	33.0	25.0
sulphate (ppm)	20.0*	20.0*	20.0*	7.1	20.0*	9.4
nitrate (ppm)	3.0	2.8	0.8	1.8	1.0	1.2
phosphorus (ppm)	5.1	5.0	29.9	14.2	18.1	19.4
organic matter (%)	1.9	0.9	5.5	2.8	1.8	4.0
copper (ppm)	15.0	14.0	5.3	8.6	9.6	1.6
zinc (ppm)	2.2	1.2	1.2	0.9	0.6	0.3